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NEW ASPECTS OF RELATIVITY

GEOMETRICAL TREATMENT OF THE VOIGT AND PAGE TRANSFORMATIONS*

By ARCHIBALD HENDERSON

3 TEXT FIGURES

(I)

On March 26 of the present year, the most precious piece of glass in the world, estimated in money value at $6,000,000.00, left Corning, New York, on its 3,300-mile trans-continental journey to Pasadena, California. This is the 200-inch telescope-eye designed for erection on Mount Palomar, north of San Diego, California. The completion of this monster eye-piece, a twelve-years task first and last, is one of the supreme triumphs of scientific, inventive, and technical skill of modern times.

The new telescope will be, it is estimated, about 360,000 times as effective as the human eye. It will plumb the inter-stellar spaces three times as far and expose a volume of space twenty-five times as vast as the 100-inch reflector on Mount Wilson will now do. But whether it will confirm the validity of the theory of relativity or determine whether the universe is at present expanding, is problematical. Queried on the former issue, Einstein replied: "Not the eye but the spirit furnishes the proof of theories."

During the past three decades, the theory of relativity has revolution-

* This paper, in substance, was delivered before the Southeastern Section, Mathematical Association of America, University of South Carolina, Columbia, April 17, 1936.

ized the thinking of mathematicians, physicists, astrophysicists, and astronomers. It has given an incalculable impetus to research, in especial along the lines of higher forms of space, tensor calculus, differential geometry, non-Euclidean geometry, light, optics, and electromagnetism. Einstein himself, Eddington, Weyl, and others have labored to generalize the field-theory conception to combine electromagnetism and universal gravitation in a logical and coherent unity. Not only is the Einstein theory of relativity being intensively studied: new theories of relativity, suggested by Einstein's pioneering and now classical contributions, are being advanced, notably by Sulaiman, Milne, and Page. These newer theories, like the older, are characterized by formal speculation and imaginative intuition; and in the last analysis assume the "uniformity of the secrets of natural law." It is no longer desirable, as Einstein has recently pointed out, for the physicist to abdicate in favor of the philosopher, in the matter of critical contemplation of the theoretical foundations of physics. "It cannot be right at a time when the very foundations of physics itself have become problematic as they are now."[1]

(II)

The foundation principles of Einstein's restricted relativity theory are: the famous Voigt transformation,[2] incorrectly ascribed to Lorentz; the invariability of a quantity known as the Riemannian space-time interval, a composite of both space and time; and the principle of the constancy of light-velocity in empty space. In his researches in elastic light-theory, Voigt in 1887 derived the famous formula, for the purpose of introducing the concept of "local time" in a mobile system and thereby establishing the validity of the wave-equation

$$\Delta\phi - \frac{1}{c^2}\frac{\partial^2\phi}{\partial t^2} = 0$$

in the mobile system. In several writings of a fundamental character, dating from 1892, Lorentz effectively established, by means of this same transformation independently arrived at, the physical equivalence

[1] Albert Einstein: "Physics and Reality." Journal of the Franklin Institute, vol. 221, no. 3, March, 1936.

[2] W. Voigt: "Ueber das Doppler'sche Princip." Göttinger Nachrichten, 1887, p. 41.

of the moving and the stationary systems, with rectilinear motion and fixed relative velocity.[3] Lorentz however was bound to the old ideas, since he used a privileged system, namely one "fixed in the ether." The revolution in ideas regarding time and space, introduced by Einstein in 1905 in his classic paper "On the electro-dynamics of moving bodies," gave a completely new interpretation of the Voigt transformation.[4] Aiming at a theory of correlativity, which has since been known under the somewhat inexpressive name of relativity, Einstein denied the existence of any privileged system in space and interpreted the two systems involved as having perfect reciprocity. Einstein treated the Voigt equations as a linear transformation in pseudo-Euclidean space-time, adjusting the time and space co-ordinates of the two systems in order to establish the invariance of light-velocity.

In 1906 Poincaré, in a treatment of the dynamics of the electron and the subject of universal gravitation, interpreted the Voigt equations as a transformation representing a rotation in space through an imaginary angle.[5] Minkowski in 1907 followed Poincaré in giving a like interpretation of the Voigt transformation;[6] but in later papers he put forward his ingenious conception of world-lines and the light-cone, usually simplified to the case of the rectangular hyperbola $c^2t^2 - x^2 = 1$, the Voigt equations constituting the transformation from this form to

[3] H. A. Lorentz: "La théorie éléctromagnetique de Maxwell et son application aux corps mouvants." Arch. Néerl. **25** (1892), p. 363; "Versuch einer Theorie der elektrischen und magnetischen Erscheinungen in bewegten Körpern" (Leyden, 1895); "Electromagnetic phenomena in a system moving with any velocity smaller than that of light." Proc. Amsterdam Acad. VI (1904), p. 809. In his "The Theory of Electrons," being lectures delivered at Columbia University, New York, in 1906 (Leipzig, Teubner, 1909), Lorentz (p. 198), after stating that Voigt's paper had hitherto escaped his attention, specifically acknowledges: "The idea of the transformation might therefore have been borrowed from Voigt, and the proof that it does not alter the form of the equations for the free ether is contained in his paper."

[4] A. Einstein: "Zur Elektrodynamik bewegter Körper." Annalen der Physik **17** (1905), p. 891.

[5] H. Poincaré: "Sur la dynamique de l'éléctron." Rend. del Circolo mat. di Palermo, vol. xxi, 1906, p. 129.

[6] H. Minkowski: "Grundgleichungen für die elektromagnetischen Vorgänge in bewegten Körper." Gött. Nach., 1908, p. 53; "Das Relativitätsprinzip." Vortrag gehalten in der math. Gesellsch. zu Göttingen, Nov. 5, 1907, published in Jahresber. d. Deutsch. Math. Ver. **24** (1915), p. 372, and in Ann. d. Physik **47** (1915), p. 927.

$c^2t'^2 - x'^2 = 1$, being the same curve referred to a (non-perpendicular) pair of conjugate diameters.[7]

(III)

The restricted relativity theory has received only slight treatment, comparatively speaking, by means of hyperbolic functions of a real variable.[8] The most thoroughgoing treatment, employing hyperbolic functions, is found in Fontené's brief work on restricted relativity;[9] but the derivation of the Voigt transformation given by Fontené bears no resemblance to the treatment which follows; nor does Fontené derive geometrically the two invariants, one absolute, the other relative, associated with the Voigt transformation. The following treatment is presented as a complete geometrical representation, by means of hyperbolic functions, of the quantities employed in the Voigt transformation, together with the two associated invariants.

Two systems, S, S,′ with axes of abscissas in coincidence, move with uniform relative velocity v along their common axis. (See Fig. 1.) Time in each system is measured from the instant ($t = 0, t^1 = 0$) when O and O^1 are in coincidence. When O^1 leaves O a light-ray is sent from this common origin along the direction of motion; and according to the observer at O the observer on the second system arrives at O^1 when the light-ray reaches C. An event occurs at the point X (x,t) in the system S.

There are four problems to be solved:

1) How far will the observer at O^1 estimate himself to be from X?
2) How long after the beginning of the journey, namely from O, will the observer at O^1 estimate that the event at X occurred?
3) What is the relative invariant of the required transformation?
4) What is the absolute invariant?

Representing the light-velocity by c, let us choose c, v, $\sqrt{c^2 - v^2}$ as proportional to coshu, sinhu, 1. Then we may set

$$\frac{v}{c} = \text{tanhu and } \sqrt{1 - v^2/c^2} = \text{sechu},$$

since $\text{sec}^2\text{hu} = 1 - \tan^2\text{hu}$.

[7] H. Minkowski: "Grundgleichungen für die elektromagnetischen Vorgänge in bewegten Körpern." Math. Ann., 68 (1910), p. 472; "Raum und Zeit," lecture delivered during the meeting of the "Naturforscherversammlung" at Cologne, Sept. 21, 1908 and printed in Physik. Zeitschrift 10 (1909), p. 104.

[8] W. Pauli, Jr.: Relativitätstheorie. (Leipzig, Teubner, 1921), 567, 623; Bibl. 3, 58, 73.

[9] G. Fontené: La relativité restreinte. (Paris, Vuibert, 1922).

At O erect a perpendicular to OO^1, and describe a circle with O as center and radius OI equal to unity. Describe a circle about O with OC as radius, and erect a perpendicular to OO^1 at O^1, meeting the circle in Q.

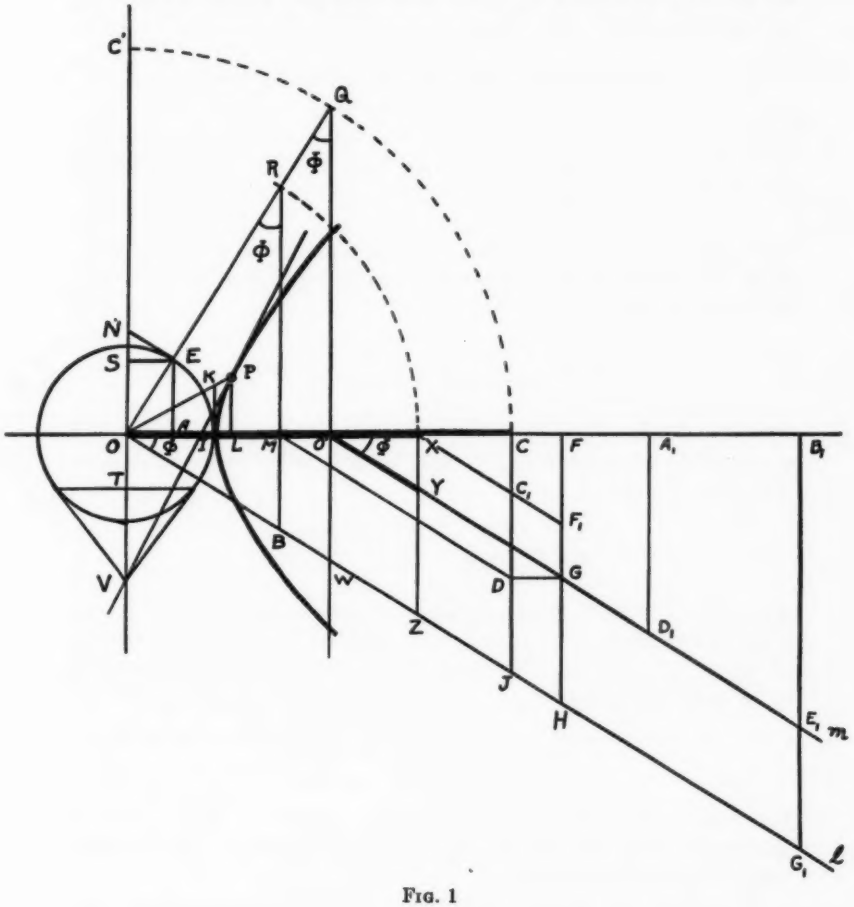

FIG. 1

Denote the angle OQO^1 by ϕ, the angle O^1OQ by θ. On OQ lay off OR = OX. Drop a perpendicular RM on OO^1. Also lay off CF = MO^1, $FA_1 = O^1X$, $A_1B_1 = OM$. Through O, M, O^1, X respectively draw lines each meeting the line OB_1 at the same angle, ϕ; and inter-

secting the verticals through M, O^1, X, C, F, A_1, B_1 in the following points: B, W, Z, J, H, G_1; D; Y, G, D_1, E_1; C_1, F_1.

Now OC = OD = ct; OO^1 = vt; OX = OR = x; O^1X = x − vt. Let OQ meet unit circle, centre O, in E; and drop perpendicular, EA, from E to line OO^1. Now we have

$$O^1Q:MR:AE::OQ:OR:OE::OO^1:OM:OA$$

Hence

$$\frac{OA}{OE} \equiv \frac{OA}{1} = \frac{OO^1}{OQ} = \frac{vt}{ct} \equiv \frac{v}{c},$$

Hence OA = tanhu. Then AE = sechu, since $\sec^2 hu = 1 - \tan^2 hu$. Draw ES parallel to AO and construct the inverse point, N, of S with respect to the unit circle. Then

$$ON \equiv \frac{1}{OS} = \frac{1}{AE} = \frac{1}{\text{sechu}} = \text{coshu}$$

Now lay off OL = ON = coshu. Also erect IK perpendicular to OO^1 and equal to OA. Then let OK meet the perpendicular to OO^1 at L in the point P. Hence

$$\frac{LP}{OL} = \frac{LP}{\text{coshu}} = \frac{IK}{OA} = \frac{\text{tanhu}}{1},$$

giving LP = sinhu. Hence the point P (coshu, sinhu) lies on the rectangular hyperbola $x^2 - y^2 = 1$, since $\cos^2 hu - \sin^2 hu = 1$. Now lay off OT = LP = sinhu. Then, taking V, the inverse of T with respect to the unit circle, we have

$$OV = \frac{1}{OT} = \frac{1}{\text{sinhu}} = \text{cschu}$$

It follows immediately that the line VP, $\text{coshu} \cdot x - \text{sinhu} \cdot y = 1$, is the tangent to the rectangular hyperbola at the point P. Here u represents double the sector AIP.

Now $O^1Y = OZ - OW$. Also

$$\sec \phi = \csc \theta = \frac{OE}{AE} = \frac{1}{\text{sechu}} = \frac{1}{\sqrt{1 - \tan^2 hu}} = \frac{1}{\sqrt{1 - v^2/c^2}}$$

Then $O^1X \cdot \sec \phi = OX \cdot \sec \phi - OO^1 \cdot \sec \phi$, which may be written $O^1Y = OX \cdot \text{coshu} - OO^1 \cdot \text{coshu}$. But

$$\frac{\text{sinhu}}{\text{coshu}} = \text{tanhu} = \frac{v}{c} \therefore v \cdot \text{coshu} = c \cdot \text{sinhu}$$

Hence

$$x^1 = \text{coshu} \cdot x - \text{sinhu} \cdot ct \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Furthermore, $O^1F = OF - OO^1 = OC + CF - (OM + MO^1) = OC - OM$. Then $O^1F \cdot \sec \phi = OC \cdot \sec \phi - OM \cdot \sec \phi$, which may be written

$$O^1G = ct \cdot \text{coshu} - OR \cdot \sin \phi \sec \phi = ct \cdot \text{coshu} - OR \sinh u$$

Hence

$$ct^1 = \text{coshu} \cdot ct - \text{sinhu} \cdot x \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

To find the relative invariant, we have $O^1G - O^1Y = YG = XC_1 + C_1F_1 = XC \sec \phi + CF \sec \phi = XC \sec \phi + MO^1 \sec \phi = XC \cdot \sec \phi + RK_1 \sec \phi = XC \cdot \sec \phi + RQ \cdot \sin \phi \sec \phi = XC \cdot \sec \phi + XC \cdot \tan \phi = XC \left(\frac{1 + \sin \phi}{\cos \phi}\right)$. Hence

$$ct^1 - x^1 = \frac{\alpha}{c}(c + v) \cdot (ct - x) \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$[\alpha = (1 - v^2/c^2)^{-\frac{1}{2}}]$$

Similarly $O^1G + O^1Y = O^1G + GD_1 = O^1E_1 - D_1E_1 = OG_1 - OW - OB = OB_1 \sec \phi - (OW + XZ) = OB_1 \sec \phi - (CJ + OX \cdot \tan \phi) = OB_1 \sec \phi - (OC \cdot \tan \phi + CB_1 \cdot \tan \phi) = OB_1 \sec \phi - OB^1 \cdot \tan \phi = OB_1 \left(\frac{1 + \sin \phi}{\cos \phi}\right)$. Hence

$$ct^1 + x^1 = \frac{\alpha}{c}(c - v) \cdot (ct + x) \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

From (3) and (4), we obtain the relative invariant

$$\frac{ct^1 - x^1}{ct^1 + x^1} = \left(\frac{c + v}{c - v}\right)\left(\frac{ct - x}{ct + x}\right) \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

To find the absolute invariant, we have $O^1G = MD = BJ$ (parallels included between parallels). Also $O^1Y = WZ$. Now $\overline{BJ}^2 - \overline{WZ}^2 = (OJ - OB)^2 - (OZ - OW)^2 = (\overline{OJ}^2 - \overline{OW}^2) - (\overline{OZ} - \overline{OB}^2) - 2\,(OJ \cdot OB - OZ \cdot OW)$. Also

$$\frac{OZ}{OJ} = \frac{XZ}{CJ} = \frac{OB}{OW}$$

$$\therefore OJ \cdot OB - OZ \cdot OW = 0$$

Hence

$$\overline{O^1G}^2 - \overline{O^1Y}^2 = (\overline{OJ}^2 - \overline{CJ}^2) - (\overline{OZ}^2 - \overline{XZ}^2) = \overline{OC}^2 - \overline{OX}^2$$

Thus we have, showing the absolute invariance of the interval

$$\overline{ds^1}^2 \equiv (ct^1)^2 - (x^1)^2 = (ct)^2 - (x)^2 = \overline{ds}^2 \quad \ldots\ldots\ldots (6)$$

This is otherwise algebraically shown by equations (1) and (2), since $(ct^1)^2 - (x^1)^2 = (\text{coshu} \cdot ct - \text{sinhu} \cdot x)^2 - (\text{coshu} \cdot x - \text{sinhu} \cdot ct)^2 = (ct)^2 (\cos^2 hu - \sin^2 hu) - x^2 (\cos^2 hu - \sin^2 hu) = (ct)^2 - (x)^2$.

It is easy to see that

$$OM = \frac{v}{c}\, x = \text{tanhu} \cdot x,$$

$$SZ = \frac{c}{\sqrt{1 - v^2/c^2}} \left(t - \frac{vx}{c^2} \right) = \text{coshu} \cdot ct - \text{coshu} \cdot \text{tanhu} \cdot x$$

Since the equations are linear in the variables, we have the absolute invariant for an infinitesimal region

$$\overline{ds'}^2 \equiv (cdt^1)^2 - (dx^1)^2 = (cdt)^2 - (dx)^2 \equiv \overline{ds}^2 \quad \ldots\ldots\ldots (7)$$

(IV)

In the opinion of some scientists, the theory of relativity cannot as yet be said to rest upon entirely stable foundations. This, too, in spite of Einstein's recent assertion that no one doubts the justification in principle of the general theory of relativity. In regard to the famous Michelson-Morley experiment, which constitutes one of the foundation stones of relativity, Dr. W. B. Cartmel of the University of Montreal has recently devised a formula which completely accounts for the results obtained by all those who have tried this experiment during the last half-century. In particular, it accounts strikingly for the conclusions of the elaborate investigations conducted by Dr. Dayton C. Miller, of

the Case School of Applied Science.[10] A determinative coefficient in Cartmel's formula for the fringe shift turns out to be equal to 1/400 in Miller's case, which accounts for the latter's finding 1/400 of the expected fringe shift and 1/20 of the expected velocity. In the admirable paper, summing up the results of his prolonged experiments, Miller concludes that there is an absolute motion of the solar system as a whole; and that this cosmic motion of the earth has a velocity of 208 kilometers per second, directed toward the "southern apex" in the constellation Dorado, the Sword Fish, about 20° south of the star Canopus, the second brightest star in the heavens, located in the midst of the Great Magellanic Cloud.[11] The combination of the orbital motion of the earth at the rate of 30 kilometers per second, with the motion of 208 kilometers per second at right angles to its orbit, gives the earth, according to Miller and Cartmel, an absolute motion through space in a spiral path. These experiments and conclusions, if eventually confirmed, will give a serious blow to the theory of relativity which postulates that no purely terrestrial experiment can be devised to detect the motion of the earth in space.

Even the constancy of light-velocity in empty space, another basic postulate of relativity, is not as yet established in the definitive sense. The last experiment to determine the light-velocity, initiated by the late Professor A. A. Michelson and completed after his death by Pease and Pearson, showed wide fluctuations of two kinds, with an uncertainty of from 3,280 to 6,560 feet. The figure for light-velocity given by this latest experiment is 186,270.75 miles or roughly 299,774 kilometers per second. Scientists are still far from realizing Michelson's dream of eliminating the uncertainty down to the last mile.

(V)

Professor Leigh Page of Yale University has recently advanced a new conception of relativity, designed not to controvert Einstein's general principle of relativity, but to broaden the bases of the restricted theory.[12]

[10] I am indebted to Dr. Cartmel for abstracts of his two papers delivered at a joint meeting of the American Physical Society and the Optical Society of America, February 21–22, 1936.

[11] Dayton C. Miller: "The ether-drift experiment and the determination of the absolute motion of the earth." Reviews of Modern Physics, vol. 5, no. 3, July, 1933. I am indebted to Dr. Miller for copies of this and a number of other papers bearing on this subject.

[12] L. Page: "A new relativity." Paper I. "Fundamental principles and transformations between accelerated systems." Physical Review 49, pp. 254–268. (February 1, 1936). Paper II. "Transformation of the electromagnetic field between accelerated systems and the force equation, *ibid.* 49, pp. 466–469. (March 15, 1936).

The restricted theory postulates the constancy of light-velocity in Euclidean empty-space; and deals with reference frames which have constant relative velocities in a straight line. Following the lead of Professor Milne of Oxford University, who in his new work[13] dispenses with the undefinable concepts of rigid measuring rods and periodic clocks, Page bases his "New Relativity" upon the constancy of light-velocity in Euclidean empty space, together with the postulated conception of a particle-observer with the capacity for deciding absolutely the time of events occurring at himself. The intrinsic conception of correlativity, expounded by Milne, is an elucidation of Einstein's laconic but somewhat vague statement: "Alle Stellen des Universums sind gleichwertig."

Einstein's fundamental postulate is that the "physical interval" between two near-by events is an absolute invariant for all reference systems. Page's theory is revolutionary, in that he has discovered, in an effectively empty world, a new category of reference systems with Euclidean geometries and constant light-velocity, which have constant relative accelerations (in the relativistic sense); but for which the physical interval, contrary to Einstein's fundamental assumption, is not an absolute invariant. This new theory, applicable to microscopic rather than to macroscopic phenomena, offers the possible prospect of acquiring a better understanding of the motions occurring in the atom.

For these systems with constant relative accelerations (in the relativistic sense), the writer suggests the name "activist" systems as contrasted with the "inertial" systems, having constant relative velocities in a straight line, of Einstein's restricted relativity. For these "activist" systems, Page has developed formulas which are the analog of the Voigt transformation of restricted relativity. For these formulas the writer ventures to suggest the name, the "Page transformation," in honor of the discoverer.

In the remainder of this paper is given, for the first time, it is presumed, a geometrical interpretation of the Page transformation and the associated invariants. The idea back of this treatment is identical with that of the first part of this paper, namely an exhibition, in geometrical terms, of the fundamental properties and relationships of the "Page transformation." As might be expected, however, the geometrical properties in the two cases are entirely different. In the former, the

[13] E. A. Milne: Relativity, gravitation, and world-structure. (Oxford, Clarendon Press, 1935).

relative invariant belongs to the finite region of the plane; whereas the "physical interval," which is an absolute invariant, holds for the infinitesimal as well as for the finite domain. In the latter, the relative invariant holds only for the infinitesimal region of the plane, whereas the absolute invariant holds only for the finite region.

(VI)

A problem which Page studies in his first paper concerns the properties of the linear reference systems adjoined to two synchronous particle-

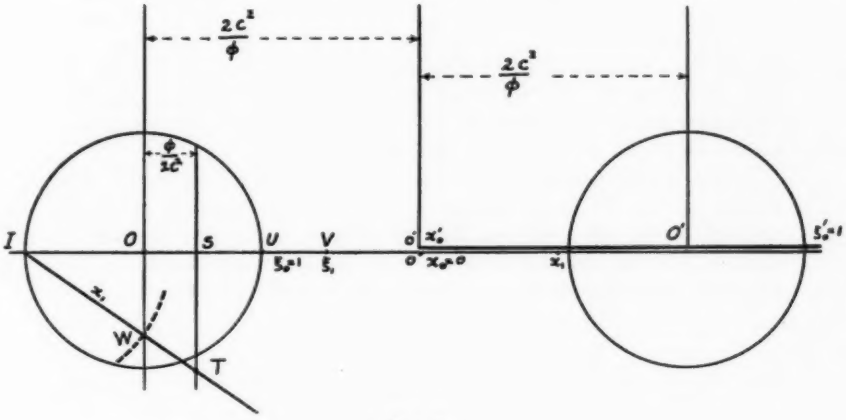

FIG. 2

observers P and P¹ which have a constant relative acceleration ϕ (in the relativistic sense). The differential equation of motion of P¹ relative to P is

$$\frac{d^2r}{dt^2} = (1 - v^2/c^2)^{\frac{1}{2}}\,\phi \qquad (1)^{14}$$

The integral of this is readily seen to be

$$1 + \phi\, r/c^2 = (1 + \phi^2\, t^2/c^2)^{1/2} \qquad (2)$$

[14] See, for example, J. Rice: Relativity. (Longmans, Green & Co., London and New York, 1923), equation (10), p. 60.

By making use of the basic equations of the Page theory, it is not difficult to arrive at the following transformation

$$x^1 = \frac{x\left(1 + \frac{\phi x}{2c^2}\right) - \frac{\phi t^2}{2}}{\left(1 + \frac{\phi x}{2c^2}\right)^2 - \frac{\phi^2 t^2}{4c^2}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

$$t^1 = \frac{t}{\left(1 + \frac{\phi x}{2c^2}\right)^2 - \frac{\phi^2 t^2}{4c^2}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

where (3) represents P^1's estimation of the distance of an event Q, and (4) represents P^1's "extended" time of the event Q. These are the formulas which will be referred to hereafter as the Page transformation by analogy with the Voigt transformation.[15]

It is now proposed to give a complete geometric representation and elucidation of this transformation, which is not attempted in Page's original paper. It is obvious that the origins of the two systems are coincident at the moment from which times in each are counted. The following substitutions are made for the sake of simplification:

$$\left.\begin{aligned} \xi &= 1 + \frac{\phi x}{2c^2}, & T &= \frac{\phi t}{2c} \\ \xi^1 &= 1 - \frac{\phi x^1}{2c^2}, & T^1 &= \frac{\phi t^1}{2c} \end{aligned}\right\} \qquad (5)$$

In the two systems, S, S^1, this is equivalent to taking new origins at the points $-\frac{2c^2}{\phi}$ and $\frac{2c^2}{\phi}$ respectively, and combining with the latter a change in the sense of the axis. It is to be noted that when $x = 0$, $x^1 = 0$, $t = 0$, $t^1 = 0$, we have $\xi = 1$, $\xi^1 = 1$, $T = 0$, $T^1 = 0$.

Corresponding to a given point (event), say Q, represented in Fig. 2 with the abscissa x, and carrying the time co-ordinate t, for the S system, are the co-ordinates ξ, and T, in the transformed system. First let us carry out the transformations of S and S^1 to systems with new origins. Clearly we have directly.

[15] L. Page: I, *ibid.*, pp. 260 *f*.

$$\frac{2c^2}{\phi}(-\xi^1+1)=\frac{x\xi-ct\cdot T}{\xi^2-T^2}$$

$$\therefore\ \xi^1=\frac{\xi^2-T^2-\frac{\phi}{2c^2}x\cdot\xi+\frac{\phi}{2c}t\cdot T}{\xi^2-T^2}=\frac{\xi^2-T^2-(\xi-1)\,\xi+T^2}{\xi^2-T^2}$$

or

$$\xi^1=\frac{\xi}{\xi^2-T^2}\qquad\qquad(6)$$

and the inverse

$$\xi=\frac{\xi^1}{\xi^{12}-T^{12}}\qquad\qquad(7)$$

Similarly,

$$T^1=\frac{T}{\xi^2-T^2}\qquad\qquad(8)$$

and

$$T=\frac{T^1}{\xi^{12}-T^{12}}\qquad\qquad(9)$$

This transformation, either from (6) and (7) or from (8) and (9), gives

$$(\xi^2-T^2)\cdot(\xi^{12}-T^{12})=1\qquad\qquad(10)$$

It yields, from (6) and (8) or from (7) and (9), the absolute invariant

$$\frac{\xi^1}{T^1}=\frac{\xi}{T}\qquad\qquad(11)$$

Furthermore, it yields a relative invariant, which may readily be found. Thus from equations (5) we have

$$dx^1=-\frac{2c^2}{\phi}d\xi^1,\qquad dt^1=\frac{2c}{\phi}dT^1$$

$$dx=\frac{2c^2}{\phi}d\xi,\qquad dt=\frac{2c}{\phi}dT$$

Hence

$$c^2dt'^2 - dx'^2 = \frac{4c^4}{\phi^2}(dT'^2 - d\xi'^2)$$

and

$$c^2dt^2 - dx^2 = \frac{4c^4}{\phi^2}(dT^2 - d\xi^2)$$

$$\therefore \frac{c^2dt'^2 - dx'^2}{c^2dt^2 - dx^2} = \frac{dT'^2 - d\xi'^2}{dT^2 - d\xi^2} \quad \ldots\ldots\ldots\ldots\ldots(12)$$

Now from (6) and (8) we have

$$dT' = \frac{(\xi^2 + T^2)\cdot dT - 2\xi T d\xi}{(\xi^2 - T^2)^2}$$

$$d\xi' = \frac{-(\xi^2 + T^2)\,d\xi + 2\xi T dT}{(\xi^2 - T^2)^2}$$

Hence

$$dT'^2 - d\xi'^2 = \frac{dT^2 - d\xi^2}{(\xi^2 - T^2)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots(13)$$

From (10) and (13) we have the relative invariant

$$\frac{dT'^2 - d\xi'^2}{T'^2 - \xi'^2} = \frac{dT^2 - d\xi^2}{T^2 - \xi^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots(14)$$

which, by means of (3), (4), and (12) may be written

$$\frac{c^2dt'^2 - x'^2}{\left(\frac{\phi}{2c}t'\right)^2 - \left(1 - \frac{\phi x'}{2c^2}\right)^2} = \frac{c^2dt^2 - dx^2}{\left(\frac{\phi}{2c}t\right)^2 - \left(1 + \frac{\phi x}{2c^2}\right)^2} \quad \ldots\ldots(15)$$

Since the physical interval $c^2dt'^2 - dx'^2$ is not an absolute invariant, Page's theory is in disagreement with the fundamental postulate on which Einstein's theory of relativity is based.

Now given x_1 and its associated time t_1, the first problem is to find their correspondents ξ_1 and T_1 in the system transformed by the two equations (5), top line. Laying off the distance $\frac{2c^2}{\phi}$ to right and left of the common origin O(O'), we find the inverse S of this point O(O') with reference to the unit circle with center O and radius OU. Describe

an arc, having IW = x_1 as radius and center I, and cutting vertical through S at the point T. Then

$$WT:IW::OS:OI$$

or

$$WT:x_1::\frac{\phi}{2c^2}:1$$

and therefore

$$WT = \frac{\phi}{2c^2}\,x_1 \qquad (16)$$

Laying off $UV = WT$, we have $OV = OU + UV$, which gives, by (3),

$$OV = \xi_1 = 1 + \frac{\phi x_1}{c^2} \qquad (17)$$

Constructing $\frac{\phi}{2c}$, knowing the value of c, we can in similar fashion find $T_1 = \frac{\phi}{2c}\cdot t_1$, from the given value of t_1.

Let us now transfer our attention to Fig. 3. We wish to give a complete geometrical interpretation of the Page transformation, given the co-ordinates of a point (ξ, T). Given two lines OU, OP^1 at right angles to each other. Then lay off, on OP^1, OS = T; and from S describe an arc with radius = ξ, cutting OU at P, giving SP = ξ. Draw the unit circle with center at O and cutting the horizontal and vertical lines through O in W and I. Construct the inverse, P_1, of P with respect to the unit circle. Join I to P and on the vertical through O lay off OP^1 = OP. Through P^1 draw a line parallel to IP cutting horizontal through O in the point U. Construct the inverse U_1 of U with respect to the unit circle.

Now

$$OP = \sqrt{\overline{SP}^2 - \overline{OS}^2} = \sqrt{\xi^2 - T^2}.$$

Also

$$OI:OP^1::OP:OU$$

$$\therefore\ OU = \overline{OP}^2 = \xi^2 - T^2$$

since $OP^1 = OP$. Again

$$OU_1 = \frac{1}{OU},$$

and

$$OP_1 = \frac{1}{OP}.$$

Hence

$$OU_1 = \frac{1}{OP^2} = \overline{OP_1^2} = \frac{1}{\xi^2 - T^2}$$

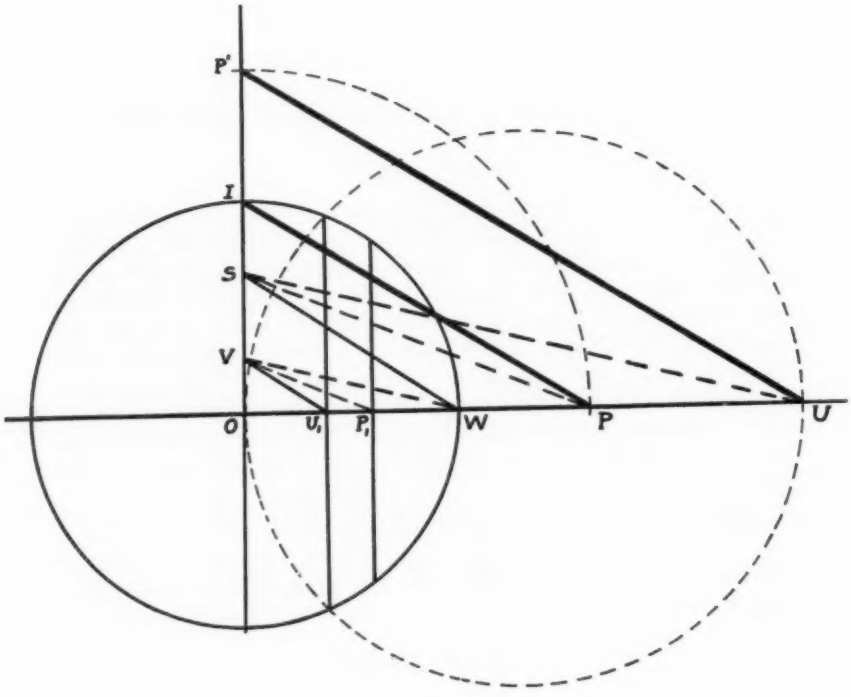

FIG. 3

Now join S to W, and through U_1 draw a line parallel to WS, cutting OP^1 at V. Draw straight lines VP_1, VW, and SU. Then $VP_1 = \xi^1$ and $OV = T^1$.

The proof follows below. Since U_1V is parallel to WS,

$$\frac{OS}{\overline{OV}} = \frac{OW}{\overline{OU_1}} = \frac{1}{\overline{OP_1^2}} = \overline{OP^2}$$

$$\therefore \frac{OS}{\overline{OP}} = OV \cdot OP = \frac{OV}{\overline{OP_1}}.$$

Hence VP_1 is parallel to SP. Also

$$OV \cdot OW = OS \cdot OU_1 = OS \cdot \overline{OP_1^2} = \frac{OS}{\overline{OP^2}} = \frac{OS}{\overline{OU}}$$

or

$$OV{:}1 = OS{:}OU, \qquad \text{since} \qquad OW = 1.$$

Therefore $OV{:}OW = OS{:}OU$, showing that VW is parallel to SU.

Now

$$\frac{OS}{\overline{OV}} = \frac{SP}{\overline{VP_1}} \qquad \text{or} \qquad \frac{T}{\overline{OV}} = \frac{\xi}{\overline{VP_1}} \quad \ldots\ldots\ldots\ldots (18)$$

Also

$$\frac{OS}{\overline{OV}} = \frac{OU}{\overline{OW}} = \frac{\overline{OP^2}}{1},$$

and hence

$$\frac{T}{\overline{OV}} = \xi^2 - T^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (19)$$

We have

$$\overline{OP^2} \cdot \overline{OP_1^2} = 1$$

and hence

$$OU \cdot OU_1 = \text{i},$$

giving

$$(\xi^2 - T^2)(\overline{VP_1^2} - \overline{OV^2}) = 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots (20)$$

Also

$$\frac{OV}{OS} = \frac{OW}{OU} = \frac{OU_1}{1} = \overline{OP_1}^2 = \overline{VP_1}^2 - \overline{OV}^2$$

$$\therefore \frac{OV}{T} = \overline{VP_1}^2 - \overline{OV}^2 \quad \ldots\ldots(21)$$

Setting $VP_1 = \xi^1$, $OV = T^1$, we have from (18)

$$\frac{T}{T^1} = \frac{\xi}{\xi^1} \quad \ldots\ldots(11)$$

From (19) we have

$$\frac{T}{T^1} = \xi^2 - T^2 \quad \ldots\ldots(8)$$

From (20), we have

$$(\xi^2 - T^2)(\xi^{1^2} - T^{1^2}) = 1 \quad \ldots\ldots(10)$$

and from (21) we have

$$\frac{T^1}{T} = \xi^{1^2} - T^{1^2} \quad \ldots\ldots(9)$$

Hence from equations (8), (10), and (11) we have

$$\xi^1 = \frac{\xi}{\xi^2 - T^2} \quad \ldots\ldots(6)$$

and

$$\xi = \frac{\xi^1}{\xi^{1^2} - T^{1^2}} \quad \ldots\ldots(7)$$

Now from the method of construction we can easily see that if we give increments to ξ and T so that the line representing $\xi + d\xi$ is parallel to SP, we shall find the line representing $\xi^1 + d\xi^1$ to be parallel to VP_1 and consequently parallel to SP. From the resulting similar triangles, six in all, we have

$$\frac{T^1 + dT^1}{T^1} = \frac{T + dT}{T} \qquad \text{or} \qquad \frac{dT^1}{T^1} = \frac{dT}{T}$$

Also

$$\frac{dT^1}{d\xi^1} = \frac{dT}{d\xi} = \frac{T^1}{\xi^1} = \frac{T}{\xi}.$$

$$\therefore \frac{\overline{dT}^{1^2} - d\xi^{1^2}}{d\xi^{1^2}} = \frac{\overline{dT}^2 - \overline{d\xi}^2}{\overline{d\xi}^2}$$

Hence

$$\frac{dT^{1^2} - d\xi^{1^2}}{\overline{dT}^2 - \overline{d\xi}^2} = \frac{d\xi^{1^2}}{\overline{d\xi}^2} = \frac{dT^{1^2}}{\overline{dT}^2} = \frac{T^{1^2}}{T^2} = \frac{\xi^{1^2}}{\xi^2} = \frac{T^{1^2} - \xi^{1^2}}{T^2 - \xi^2}$$

and

$$\frac{dT^{1^2} - d\xi^{1^2}}{T^{1^2} - \xi^{1^2}} = \frac{\overline{dT}^2 - \overline{d\xi}^2}{T^2 - \xi^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots (14)$$

Thus, starting with x_1, t_1 we can find ξ_1, T_1 from Fig. 2; and from ξ_1, T_1 we can find $\xi_1{}^1$, $T_1{}^1$ from Fig. 3. Then $\xi_1{}^1$ can be laid off from O^1, center of the unit circle at the right of Fig. 2; and with it is associated the time $T_1{}^1$.

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SOME PRIMITIVE MOSS-MITES OF NORTH CAROLINA

By Arthur Paul Jacot

Plate 1

The moss-mites are regarded by the Germans as a supercohors of the suborder Sarcoptiformes (10, p. 95). The supercohors Oribatei is divided by them into twenty families. In the last edition of Pratt (8, p. 516) the moss-mites are presented by Ewing as the Galumnidae (casting out the term Oribata). I have found a middle course more convient, placing the entire group, as Banks did, in the superfamily Oribatoidea.

In 1932 Trägardh (9) described a new species of primitive mite which he secluded in a new suborder. A few months later Grandjean (2) described two related species, and pointed out that Berlese had already described three others, and that these mites were all characteristically moss-mites though presenting certain primitive characters.

I now present my more simple classification, applicable to the genera of the eastern United States and Europe. It will be noted that some of the groups I formerly regarded as families are now reduced to subfamilies, while subfamilies are reduced to tribes. The tendency in Europe has been to make up accessory groups above family rank introducing such terms as subphalanx, phalanx, superphalanx, subcohors, cohors, and supercohors. My course is to abolish these groups foreign to systematic zoölogy and use the group name tribe, so common and satisfactory in entomology. Moreover some of these groups are highly artificial. For instance the family Nanhermanniidae is based on the fusion of the adanal covers with the notogaster (3, p. 20). The genus Trhypochthoniella bridges the Trhypochthoniinae and the Malaconothridae. I see no reason for placing Gustavia and Zetorchestes in special families any more than Suctobelba, Pelops and others. Other genera have since been found which bridge many of the gaps which formerly were thought to demark the larger groups. All group names are formed from the oldest valid genus within that group, and it stands for the type of the group.

Grandjean is now working on the phylogeny of the Oribatoidea.

Although his results are of considerable interest they do not at present promise to be practical. The present arrangement claims to be simple and easily handled, without regard to evolutionary relations.

Superfamily ORIBATOIDEA

Tyroglyphina (4, p. 208) with a pair of specialized bristles (pseudostigmatic organs) on posterior part of cephaloprothorax each springing from cuplike depression (pseudostigmata), or with large anal and genital apertures each of which is closed by at least one pair of sclerotized plates, or with both.

Type: *Oribata* (6, p. 65).

Key to Families (Adults)

1. Legs capable of being drawn into anterior part of notogaster, and covered by the cephalon (aspis).....*Phthiracaridae*
1. Legs incapable of such retraction..... 2
2. Form elongate; parasterna IV nearly as long as broad; genital aperture so posterior in position (by the great expansion of parasterna IV) that ovipositor is directed posteriad within the abdomen, near the anal aperture *Eulohmanniidae*
2. Parasterna IV slender; genital aperture near parasterna IV; ovipositor directed anteriad within the body.....*Oribatidae*

I had formerly recognized the Epilohmanniidae but find that Eulohmannia belongs in this family and has precedence, thus necessitating the change in family name.

Key to Subfamilies and Tribes of Oribatidae (Adults)

1. Mandibles projecting conspicuously beyond rostrum; without distinctly differentiated notogaster.....*Parhypochthoniinae*
1. Mandibles covered by rostrum, or, abdomen with a distinct notogaster.. 2
2. Anal and genital apertures occupying most of the abdomen behind parasterna IV, broadly contiguous, the anal aperture usually narrowing posteriad through the progressive narrowing of the V-shaped ventral plate..... 3
2. Anal and genital apertures smaller, more or less quadrate, usually widely separated, sometimes touching, if apertures are broadly contiguous then legs are long and very slender..... 5
3. Dorsum of abdomen with one or more transverse divisions...*Hypochthoniinae*
3. Dorsum of abdomen without transverse divisions.....*Camisiinae* 4
4. Integument pale.....Lohmanniini
4. Integument brown to black.....Camisiini
5. Notogaster without lateral expansions, anterolateral corners sometimes produced as an outjutting boss, ridge or blade..... 6
5. Notogaster with thin, lateral expansions which are usually bent ventrad to cover at least the leg insertions.....*Galumninae* 8

6. Notogaster smooth, if granular then lamellae are absent to poorly developed *Oribatinae* 7
6. Notogaster variously sculptured, if granular then lamellae are well developed *Cepheinae**
7. Lamellae absent or developed as low ridges or nobs.....Oribatini
7. Lamellae developed as blades, free along lateral edge.....Gustaviini
8. Mandibles styliform or chelae minute; notogaster roughed by accumulation of a coating of extraneous matter or otherwise.....Pelopini
8. Mandibles broad throughout, chelae massive; notogaster smooth..... 9
9. Lamellae attached to cephaloprothorax only at their base and posteromesal edges, and developed as broad blades with median edge free or more or less fused, covering most of the cephaloprothorax.....Achipteriini†
9. Lamellae not so highly developed..... 10
10. Pteromorphae produced far anteriad of abdomen even to ends of lamellae, or joined over the cephaloprothorax to form a broad bridge..... 11
10. Pteromorphae not extending far anteriad of abdomen.....Ceratozetini
11. Pteromorphae joined to each other along anterior edge of abdomen, forming more or less of a bridge over the cephaloprothorax.....Oripodini
11. Pteromorphae very large, extending downward to cover part of ventral plate and forward to cover part of cephaloprothorax; legs received in cupboards in sides of abdomen and entirely enclosed by the pteromorphae; lamellae small to absent.....Galumnini

* Cepheus has page precedence over Carabodes.
† Achipteria has precedence over Oribatella.

The following are new to science. The types will be deposited at the National Museum.

Genus GEHYPOCHTHONIUS gen. nov.

Parhypochthoniinae without apophyses on sides of abdomen, with one transverse suture across dorsum of abdomen, bihamate ungues, anal covers with two bristles each, paranal covers with three bristles each, genital covers with six median and three lateral bristles.

Type: *Gehypochthonius rhadamanthus* sp. nov.

Gehypochthonius rhadamanthus *sp. nov.*

Figures 1 and 2

Animal entirely white or glassy (resembling an immature); size: total length (including mandibles) 0.3 mm., greatest width 0.09 mm., distance between pseudostigmata 0.04 mm.; dorsal bristles rather short (shorter than tarsus I), straight, of equal caliber throughout; rostral bristles borne on a small, triangular projection (the rostrum) which

sets at a lower level than anterior edge of cephaloprothorax; major exopseudostigmatic bristles as long as rostral, inserted fairly close to pseudostigmata; minor exopseudostigmatic bristles very short, inserted below pseudostigmata; mandibles broadly exposed, with a depressed bristle over the chela and one farther back (figure 1); palps four segmented, not including base (figure 1), their tarsus with a curved spine on dorsal face; pseudostigmata with well formed rim; pseudostigmatic organ longer than longest bristle, head swollen, armed with four short, stout bristles, in each of four longitudinal rows, spaced almost their length from each other.

Notogaster divided by transverse fold; anterior section with twelve bristles arranged in two transverse rows, a3 slightly anterior to the others; posterior section with sixteen bristles on dorsal aspect, and two on ventral face, the dorsal bristles arranged in three transverse rows the ends of which curve anteriad. Thus the species is meritrich (totaling only thirty notogastral bristles) (3, p. 22).

Bristles of anogenital area arranged as in figure 2. Apodemata III and IV each with three bristles (figure 2); I am able to see but two bristles on apodemata II and three on apodemata I, in the none too satisfactory material before me. Legs I as in figure 1; tarsi I with a long, curved spine springing from near proximal end (as in so many soil Oribatidae). Tarsal hooks fairly large, subequal, with a minute point between their proximal ends.

Thus this species has the bristle arrangement and pseudostigmatic organs characteristic of the Hypochthoniinae but the uncovered mouth parts of the Parhypochthoniinae. I place it in the latter subfamily as a highly specialized species approaching the Hypochthoniinae. It is capable of considerable extension and telescopic retraction at the mid-thoracic region. The figure shows the animal very much retracted.

Material examined: Twenty-five specimens from soil, two to five inches deep, of Andropogon sod (upper inch removed), old-field abandoned twelve years, Bent Creek, Pisgah Forest, North Carolina; taken February 6th, 1935, slide 34F23·2–5 (*cotypes*). Five specimens from lower part of F-layer of isolated, pastured and trampled forty-year-old, short-leaf pine stand, two miles beyond Bent Creek on the Asheville-Brevard road; taken October 15th, 1934, slides 34F10·3P1, -P2, and -R2. One specimen from earth of close-cropped pasture sod near the preceding, slide 3453A. One specimen from soil of eighty-year-old pine-oak woodland, Bent Creek Experimental Forest; taken January 7th, 1935, slide 34F21–10. Six specimens from a root one inch in diam-

eter and six inches long, four inches below the surface, same spot as preceding, slide 34F21r2.

This species is thus distinctly a dweller in the soil and I take particular pleasure in naming it after Rhadamanthus, one of the judges of the underworld.

Genus EOBRACHYCHTHONIUS gen. nov.

Hypochthoniinae resembling Brachychthonius but with ventral plate divided by a transverse suture, and with four small plates along sides below the notogastral plates (figures 3 and 4).

Type: *Eobrachychthonius sexnotatus* sp. nov.

Eobrachychthonius sexnotatus, *sp. nov.*

Figures 3 and 4

Color rather bright yellow, rostrum colorless; size of a female: length 0.27 mm., breadth 0.197 mm.; bristles medium long, fine, tapering; major exopseudostigmatic bristles as long as lamellar, inserted on a sclerotized ring (figures 3 and 4) which projects well beyond surface of cephaloprothorax; minor exopseudostigmatic bristles indicated by an insertion; pseudostigmatic organ clavate, studded with short bristles (figure 3); center of vertex with six symmetrically spaced areoles; two or three others grouped about exopseudostigmatic bristle ring.

Notogaster nearly as broad as long, much broader than cephaloprothorax, anterior edge with a small projection; bristles a2, b2, and b3 inserted on periphery of plate below a sclerotized ridge; a3 inserted on anteriormost lateral plate; bristles c2, d2, and e2 also situated at edge of their plates below a sclerotized ridge; other bristles and areoles disposed as in figures 3 and 4. A bristle near posterior corner of posterior ventral plate. If the lateral plates and the two ventral are regarded as parts of a notogaster and of a ventral plate which have become fragmented, the species is more specialized than species of Brachychthonius because the fragmentation has gone further. If these additional plates are regarded as parts of a fragmented notogaster then the three plates of the dorsum are also parts of a fragmented notogaster and thus do not indicate a primitive segmented condition. It seems more reasonable, however, to adopt the view that all these plates are of primitive origin. Since dorsal plate I-II subtends two laterals, these two laterals seem to corroborate the view that dorsal plate I-II (the post-thoracic) is formed of two fused transverse plates. Moreover there is a single plate beneath

dorsal plate III and a small plate beneath dorsal plate IV. To be consistent, the two ventral plates must likewise be regarded as a primitive condition and consequently that the ventral plate of the higher oribatoids is made up of two plates and that the bristle thereon is a ventral plate bristle.

Bristles of ventral aspect as usual in this subfamily but anal covers with their two bristles inserted on anterior half; genital covers with the anterior bristle of lateral row inserted quite close to median row. Apodematal bristles as in figure 4.

Palps four segmented (in addition to basal segment).

The females seem to bear but one egg at a time.

Cotypes: Eleven specimens from Andropogon sod, from near top of Glen Bald, Bent Creek Experimental Forest; taken April 17th, 1935, slide 34F31–10.

Eobrachychthonius latus **comb nov.** (1, p. 220, pl. 19, fig. 38) from Lake City, Florida, differs by having four areoles on vertex and, if the figure is accurate, no other areoles, no rostral bristles (!), and notogastral bristles slightly differently distributed. As Berlese has omitted the bristles of lateral plate I and bristle c2 (of dorsal plate III), the absent rostrals may also be an oversight.

An only specimen from grass cover of a hill at Marshall, Illinois, taken January 2nd, 1933, by Frison and Mohr, slide 33IS1/2 # 19d, is identical except that it lacks the areoles.

Hypochthonius rufulus carolinicus *subsp. nov.*

Differs from the species in that the pectinations of the pseudostigmatic organs number from fifteen to nineteen (even to twenty-three) while those of the species (of Europe) number from six to seven.

In 1934 (5, p. 260) I described a northern subspecies characterized by having but three to four pectinations. I also stated that insertions of bristles c1 were on the same transverse plane as c2 or more posterior. I now find that this character is not as constant or definite as might be desired. There is however, another character which is more obvious and seems to be quite constant, namely, the insertions of bristles b2 are about half way between b1 and b3 (though more posterior) while in the species the insertions are much nearer b3. This difference holds for both of the American subspecies, and for *Hypochthonius luteus* (7, p. 343).

The notogastral bristles of *H. r. carolinicus* are closely, more conspicuously, and more roughly barbed than in the species.

Material examined: Six specimens from litter of old-field woodland, Bent Creek Experimental Forest; taken September 20th, 1934, slides 34F4·3–5 (*cotypes*) and 34F4·1–19.

APPALACHIAN FOREST EXPERIMENT STATION,
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PLATE 1

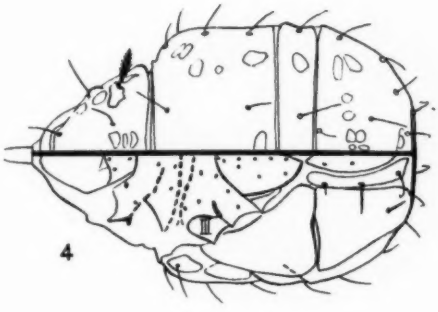
Gehypochthonius rhadamanthus *gen. et sp. nov.*

Fig. 1. Lateral aspect, legs II to IV omitted; × 466.
Fig. 2. Ventral face of abdomen; free hand.

Eobrachychthonius sexnotatus *gen. et sp. nov.*

Fig. 3. Lateral aspect, legs II to IV omitted; × 376.
Fig. 4. Dorso/ventral aspects, legs and mouth parts omitted; × 285.

PLATE 1



A NEW MULTIPLE CONSTANT TEMPERATURE APPARATUS FOR EXPERIMENTAL WORK IN BIOLOGY[1]

By R. E. Coker, Professor of Zoology
and E. W. Constable, Sometime Fellow in Chemistry
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Plates 2, 3, and Two Text Figures

The maintenance of precise constant temperatures at levels above room temperature presents relatively little difficulty, but when temperatures below or about the general level of room temperatures are required, the problem is much more complex. It is not readily solved by the use of "cold rooms," except as one may set heat-controlled baths within a cold room having a temperature below the minimum to be maintained in the several baths. There are several types of apparatus in which a ladder-like series of constant temperatures is maintained between fixed extremes, but in most of these the intermediate temperatures are not subject to strict individual control.[2] In connection with experimental work with Entomostraca it was desirable to have an apparatus to meet the following qualifications: (1) It should possess several similar chambers; (2) in each chamber the temperature should be maintainable at any desired level without regard to room temperature or to the temperatures in other chambers; (3) low or high temperatures within the range of metabolic activity of the animals should be available; (4) constancy for indefinite periods should be possible; and (5) precision to a fraction of a degree at least should be attainable. It was desirable also that the apparatus should be compact enough to be kept in a room of ordinary size, that it should be capable of being moved if necessary and that it should not be too expensive. A series of constant temperature rooms with several refrigerating units was beyond the

[1] The construction of the apparatus was made possible by a grant from the Rockefeller Fund for Research in Pure Science in the University of North Carolina. We are glad to acknowledge the courtesy of the Department of Chemistry of the University of North Carolina in permitting the building of the apparatus in its shop.

[2] See Coker, R. E., "Reactions of some freshwater copepods to high temperatures," in Journal of the E. M. Sci. Soc. **50**: 143–159, 1934, and references therein cited.

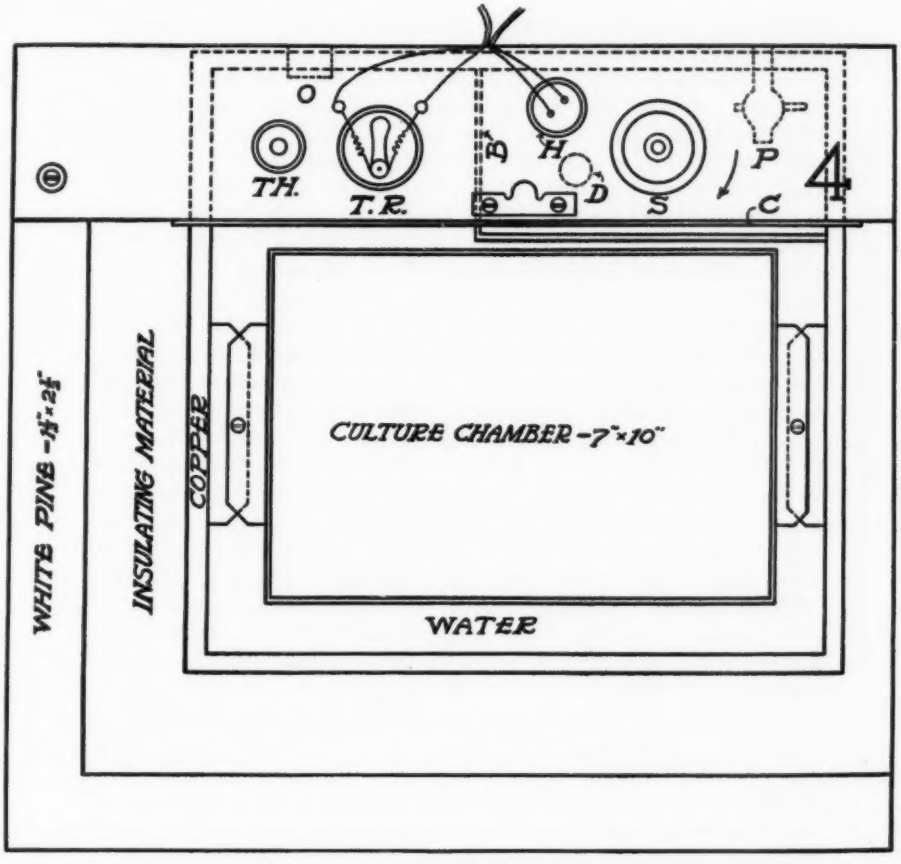
range of feasibility and a single low temperature room housing several heated baths was also impracticable.

The solution of the problem was sought in a multiple chamber apparatus, each chamber to be well insulated, supplied with water circulated from a single refrigeration chamber and equipped with its individual heating and control units. The apparatus designed and constructed is here illustrated and briefly described. The means available made it necessary to limit the number of operating chambers to six, but the design will permit a greater number if desired.

Our apparatus as a whole is 6′ 4″ long, 3′ wide and 16½″ high (or 24″ to top of motor). To make the doors of the chambers convenient of access the apparatus is set on a skeleton stand 21″ high, so that the top is about 38″ above the floor. The size, exterior design and finish are such as to make a presentable piece of laboratory furniture (pl. 2). Actually we have the compressor of the refrigerating unit set on the floor nearby (out of view in pl. 2), but it could as well be placed on a base attached to the support and beneath the chambers, if this were desirable in the interest of compactness and appearance. To remove the apparatus from one room to another it would be necessary only to disconnect two electric lines, drain out the water into tubs, transfer the apparatus in two or three parts (three by the present plan of installation), refill from the tubs, and make new connections to electric outlets in the second room. In other words, the apparatus can be moved with little more difficulty than is involved in moving a large domestic electric refrigerator, although it occupies more floor space than the latter.

The photographic illustrations (pls. 2 and 3) and the plan (figs. 1 and 2) make an extended description unnecessary. In one end is a copper-lined refrigeration chamber, or reservoir 27″ x 18″ x 12″, interior dimensions, containing about 20 gallons of water and glycerine mixture. The glycerine is added to prevent formation of ice on the refrigerating coils and to make possible a bottom temperature below 4°C., which is not obtainable without the use of an anti-freeze mixture. At present the mixture is about 11% glycerine. The temperature in the reservoir is thermostatically controlled, an automatic expansion valve governing the compressor. Accurate control of temperature in this chamber is unnecessary, but the bottom temperature here should be a little below the minimum desired in any operating chamber.

An electrically-driven centrifugal automobile pump circulates water from the bottom of the reservoir through a pipe runnning through a median conduit to the other end and having a lateral outlet to each operating chamber. On each of these outlets, and within the copper-



TOP VIEW (LID REMOVED)

TEXT FIG. 1. PLAN OF CHAMBER NO. 4, TOP VIEW WITH LID REMOVED: PETCOCK (P), DRAIN (D), OVERFLOW (O), AND WALL OF DRAFT TUBE (B) SHOWN IN PROJECTION

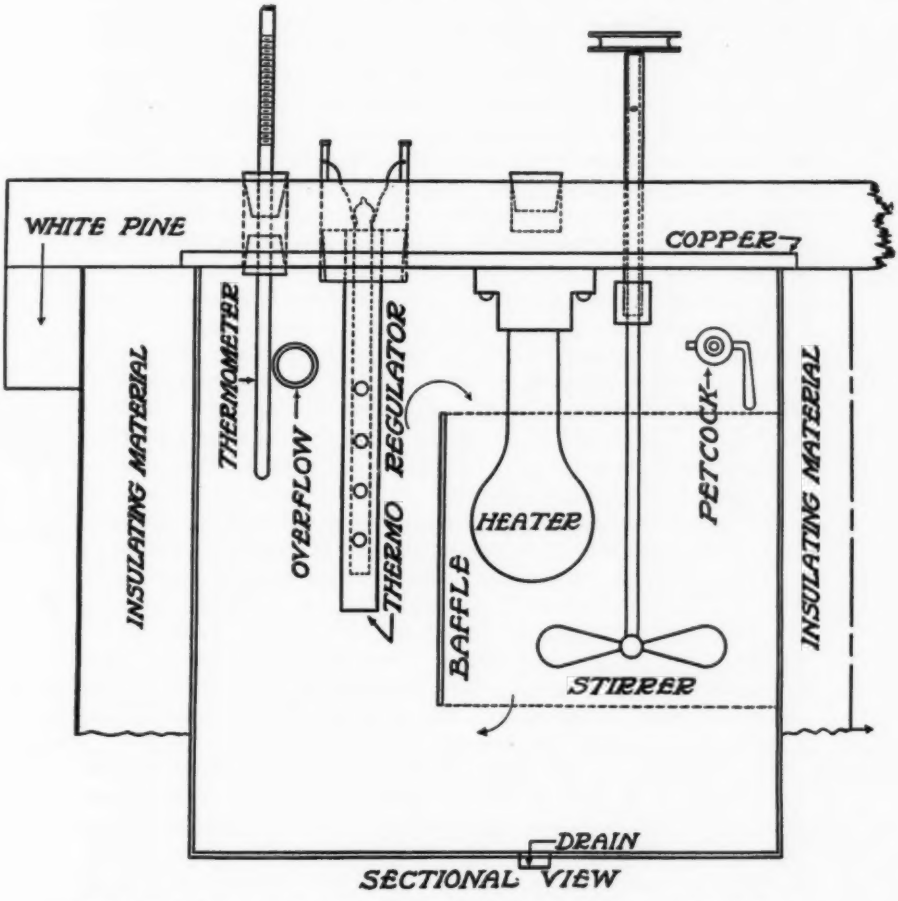
Th, socket for thermometer; *TR.*, thermoregulator; *S*, socket for stirrer shaft; *C*, copper lining reflected up; *H*, heater.

lined operating chamber (fig. 1 and pl. 3, below) supplied by it, there is an ordinary petcock (P)[3] which is regulated by hand. Strict calibration

[3] The letters in parentheses refer to corresponding letters in fig. 1.

of flow from the petcock is not requisite; it is only necessary that the flow should be at least adequate to compensate for the loss of heat by escape through the insulation of the chamber or otherwise, with a margin of safety. Actually the heat loss has been found to be much less than was expected, so that a drip, or at most a dribble, from the cock is generally all that is necessary. The proper discharge at the cock is readily determined by trial within a few minutes at the time the temperature in a given chamber is first fixed. Thereafter, the cock should require no attention. In practice we so adjust the flow that the heating unit, a submerged lampbulb, is not "off" for more than three to five minutes at a time. (It is "on" for 30–60 seconds at a time.) The excess water in the chamber discharges through a small overflow pipe (O) into a return main in the pipe conduit which leads back into the refrigerating reservoir at the end; thus, the same mixture is used over and over again, and whatever heat is acquired in the several chambers is removed in the reservoir. The heating unit in every operating chamber is a light bulb (fig. 2 and pl. 3, below) screwed into a socket (H) fixed in the ceiling of the chamber, the bulb itself being immersed in the bath liquid. The region around the bulb is fenced in by a copper partition (B) terminating, above, about $\frac{3}{4}$ inches below the surface of the liquid and, below, about 2 inches above the bottom of the chamber. Into this partially enclosed mixing space, or draft tube (see fig. 1 and pl. 3, below), falls also the drip of cold liquid from the petcock. Between the heater and the cold drip there is a propeller-type stirrer (S) of copper in continuous rotation at a speed of 600 r.p.m. Warm and cold water are thus promptly and thoroughly mixed and driven to the bottom of the draft tube to flow rapidly out in all directions over the bottom, up along the sides and back into the draft tube over the top of its wall. The several stirrers are driven by belts running from as many pulleys on a central shaft to pulleys at the top of each stirrer shaft (pl. 3, below). Both the main stirrer shaft and the pump in the refrigeration chamber are driven by individual belts from a common motor, a feature of safety, convenience and economy. We use a $\frac{1}{6}$ H.P. motor mounted on rubber to dampen vibration. Stoppage of electric current for any length of time would, of course, permit a slow fluctuation of temperature but this is a contingency to be faced with any electrically operated heating or cooling unit. It is significant that in this apparatus, interruption of current will cut off both heat and the circulation of the cooling medium. The insulation is then sufficient to maintain approximate constancy for a number of hours.

The temperature chamber proper, our culture chamber (fig. 1 and pl. 3, below, left) is a copper vessel, 10″ x 7″ x 9½″, partially immersed



TEXT FIG. 2. SECTIONAL PLAN OF A SINGLE TEMPERATURE CHAMBER IN REAR PART

in the liquid of the operating chamber which is 12″ x 12″ x 12″, and kept in place by a bolt on each side screwed through one copper flange attached to the outside of the wall of the temperature chamber near the

top and another attached to an inner wall of the operating chamber at the same level.

It is obvious now that the temperature of the air within each chamber is governed by that of the thoroughly mixed liquid surrounding it and that this in turn is controlled roughly by the inflow of cold mixture at the petcock and more precisely by the heating unit. The regulation of the operation of the heater is the primary consideration and will be explained in detail. First, however, it may be emphasized that the extensive use of copper in the lining of the chamber, in the wall of the draft tube, and in that of the temperature chamber proper, insures rapid conduction of heat to all parts, while the use of the electric lamp as a heating unit eliminates much of the lag that characterizes some heating coils.

The 110 volt heater is controlled by a relay which operates on a 6 volt, 6 milliampere circuit, this low current being necessary because of the delicacy of the mercury thermoregulator (TR), by which the relay in turn is controlled, immersed in the bath. The six relays, one for each chamber, are set up neatly in the control box (pl. 3, above), which for convenience is attached to the apparatus at the end opposite to the refrigeration reservoir (pl. 2). The low voltage current is derived from the regular lighting circuit through a small transformer, a rectifier and a condenser (reducing voltage and converting A.C. to D.C.). The plan of control is essentially as follows: When the capillary column of mercury in the thermoregulator of an operating chamber rises to the level of the electrodes, the low voltage circuit is closed, magnetizing the relay and opening the switch to break the 110 volt circuit and cut off the heater. When the capillary column of mercury falls the least bit, the low voltage circuit is broken, releasing the switch, and bringing the heater back into operation. The thermoregulators are readily adjustable to any desired temperatures.

The wiring plan is such that, save for the thermoregulators, all controls having to do with the heating units (the vital part of the mechanism as regards precision) are installed in the previously mentioned control box. This box 10″ x 14″ x 3″ (pl. 2 and pl. 3, above) contains, therefore, a transformer, a rectifier, a condenser, 6 relays, and 6 small double-pole tumbler switches, each of the switches governing both a heating circuit (110 V) and a control circuit (6 V) for an individual chamber.

Precision in temperature control for any chamber is conditioned, first, by the efficiency of the thermoregulator, and those used are specified

by the manufacturers to have an accuracy within 0.1°C.; and, second, by the effectiveness of the mechanisms employed for the uniform distribution of temperature within the chamber. The second feature is the more difficult to measure, but it seems to be efficient within 0.1°C.

A contingency to be avoided is the burning out of a light bulb. We now employ bulbs with carbon filaments because of their greater heat generation (a quality associated with inefficiency in lighting). If the bulbs are changed once in two or three months there is little likelihood of failure of the heating unit.

Within ordinary limits the temperature of any one of the several chambers may be set at any level regardless of the temperature maintained in any of the other chambers and it may be changed at any time by adjustments that include merely a small alteration in the flow of water at the petcock and the resetting of the thermoregulator; such adjustments ordinarily require but a few minutes to effect. The temperatures we have needed to employ up to the present time have been between 9° and 30°C. Merely for a trial, the senior author set one chamber at 51° and another immediately facing it at −1.5°C. There was no difficulty in maintaining constant temperatures of the water in the two compartments running simultaneously during a period of several days. In the low compartment ice formed on the floor of the culture chamber proper, but not in a beaker placed therein. We assume that with such extremes supplemental internal insulation would be required for precision of control, and presumably this could be arranged without special difficulty.

It is obvious that much depends upon many details of design and construction with reference to wiring, to the packing and lubrication of shafts passing through the top of the cabinet, to arrangements for packing the pump and preventing any leakage of oil from it into the reservoir, to the return of overflow from the several chambers, to insulation, fitting of covers, etc. To describe all of these details would extend the description to too great a length. For the apparently successful solution of the baffling problems of detail as well as for a large measure of the general design, credit should be given to the junior author.

We did not find on the market thermometers exactly adapted for use in the apparatus, but the Taylor Instrument Company has made for us some thermometers with a long stem and a scale reading in tenths of a degree from 0° to 40°C., the lowest reading on the scale being about three inches above the upper limit of immersion. The space between

the upper limit of immersion and the bottom of the scale provides for passage through the insulation of the apparatus and the long stem makes the tenth degree scale marks sufficiently well spaced for precision in reading.

SUMMARY

There is described a multiple constant temperature apparatus in which the temperature of each chamber is quite independent of any other, in which temperatures below room temperature or above may be maintained with equal facility, in which precision to a fraction of a degree can be maintained for indefinite periods, and in which each chamber offers complete flexibility as to temperatures within a wide range.

PLATE 2

MULTIPLE CONSTANT TEMPERATURE APPARATUS

The compressor, on the floor beyond the apparatus, is not visible.

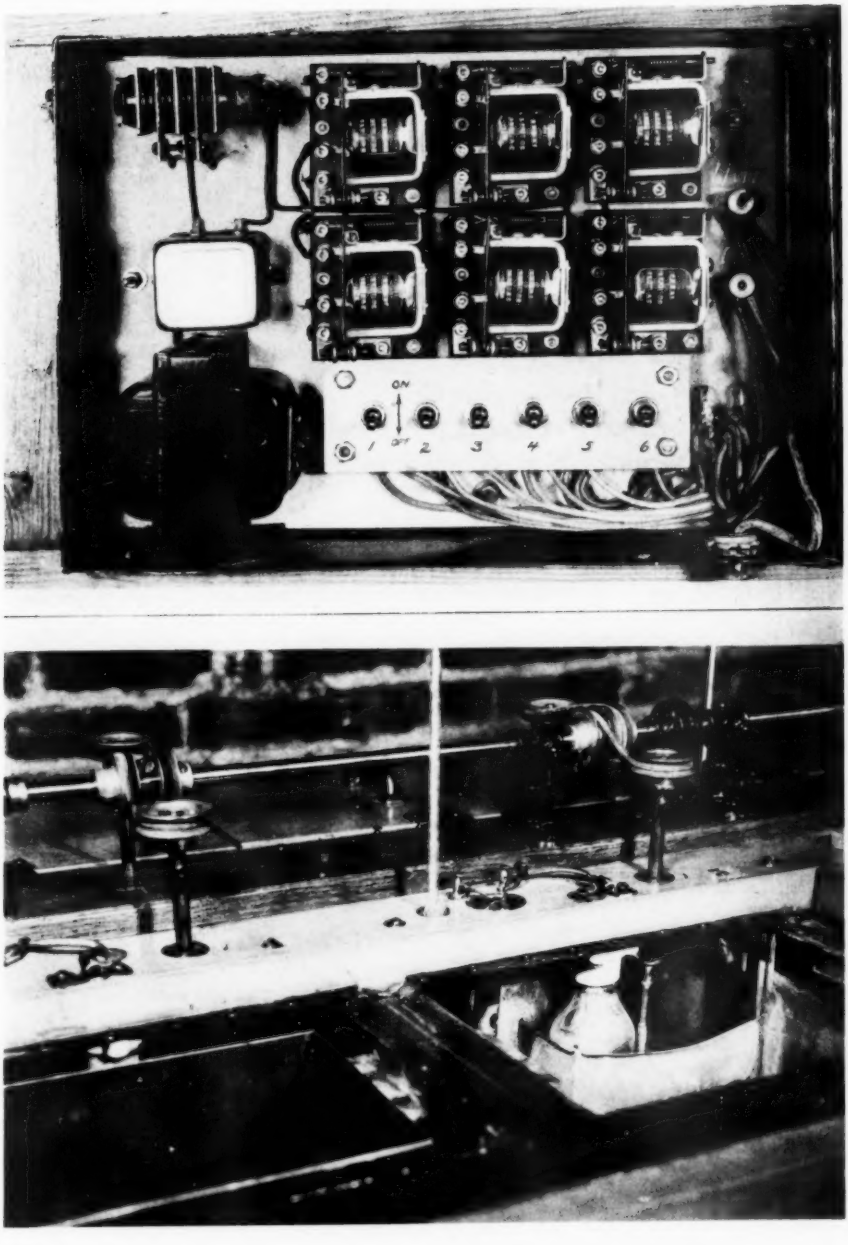
PLATE 3

(Above) Interior of control box showing, *left*, rectifier, condenser, and transformer, and, *right center*, 6 relays and 6 trip-switches, with some of the connecting wires.

(Below) Top view of portion of apparatus, with lids removed from chambers Nos. 4 and 5. The culture chamber has been removed from No. 5 to expose the draft tube enclosing, from right to left, heater, stirrer shaft, and petcock.

PLATE 2

PLATE 3



RECENT FORAMINIFERA FROM NEAR BEAUFORT, NORTH CAROLINA

By WADE H. HADLEY, JR.

ONE TEXT FIGURE

The species of foraminifera listed below were obtained from shallow water dredgings and shore sands collected in the area of Beaufort, N. C., during the summer of 1933. The writer is indebted to the U. S. Bureau of Fisheries and to Dr. Herbert F. Prytherch, Director of the Bureau's Biological Station at Beaufort, N. C., for cooperation and the use of facilities which made these collections possible.

Stations from which material was collected for this study:

Sta. No. 1—Just west of sea buoy off Beaufort Inlet. Bottom sample taken in 40 feet of water.

Sta. No. 2—Directly off Atlantic Beach, one mile from shore. Bottom sample taken in 30 feet of water.

Sta. No. 3—Sand from Shackleford Beach, collected in the area between tides.

A species of *Bolivina* occurs in the dredgings from the Beaufort area which appears to be new and is here described as *Bolivina beaufortana* n. sp.

Species recorded from the above three stations

	Station		
	1	2	3
**Quinqueloculina costata* d'Orbigny		R	
Quinqueloculina cf. *flexuosa* d'Orbigny	C	C	C
**Quinqueloculina lamarckiana* d'Orbigny	C	C	
Quinqueloculina poeyana d'Orbigny	C	C	
**Quinqueloculina* cf. *seminula* (Linnaeus)	C		C
**Spiroloculina planulata* (Lamarck)		R	
Guttulina spicaeformis (Roemer) var. *australis* (d'Orbigny)	C	C	
Elphidium gunteri Cole	C	C	C
**Elphidium incertum* (Williamson)	R	C	
**Elphidium poeyanum* (d'Orbigny)	C	C	C
**Nonion grateloupi* (d'Orbigny)	C	C	R
**Angulogerina occidentalis* (Cushman)		R	
Bolivina beaufortana n. sp.	R	R	

	Station 1	2	3
**Reusella spinulosa* (Reuss)		R	
**Discorbis subaraucana* Cushman	C	C	
**Eponides mansfieldi* Cushman	R	R	
**Rotalia beccarii* (Linnaeus) var. *parkinsoniana* (d'Orbigny)	R	R	C
Rotalia beccarii (Linnaeus) var. *tepida* Cushman	C	C	R
Globigerinoides cf. *sacculifera* (H. B. Brady)	C	C	
**Orbulina universa* d'Orbigny	R		
**Globorotalia menardii* (d'Orbigny)		R	
**Cibicides concentricus* (Cushman)	C	C	C
**Dyocibicides biserialis* Cushman and Valentine		R	

Frequency: C—common; R—rare.

Species marked (*) have been reported from beds of Miocene age.

Time range of species: Of the 23 species listed above, 16 occur in beds of Miocene age and younger along the Atlantic coastal area adjacent to the region where they are now living.

Genus BOLIVINA d'Orbigny, 1839

Bolivina beaufortana new species

Small, elongate, moderately compressed; periphery rounded; initial end blunt, test widening but slightly toward the apertual end, sides almost parallel; three or four pairs of chambers distinctly visible and making up most of the test; individual chambers subspherical, slightly inflated and separated by depressed sutures; each chamber decorated with about nine delicate, sharp, longitudinal costae which are limited to the individual chambers and develop into spinose projections at their lower extreme; the greatest concentration of spines is on the early portion of the test; wall thin, calcareous and hyaline; aperture an elongate slit lying in the plane of compression, surrounded by a slightly elevated lip and extending from the apex to the base of the final chamber.

Length—.40 mm.; greatest width—.15 mm.; thickness—.11 mm.

Holotype is from just west of sea buoy off Beaufort Inlet; depth of water— 40 ft. Rare at Stations 1 and 2. A topotype of this species has been deposited in the Department of Geology, University of North Carolina, Chapel Hill, N. C.

Bolivina beaufortana differs from *Bolivina pulchella* (d'Orbigny) of Cushman (Carnegie Inst. Washington Publ. No. **311**: 25, pl. 1, figs. 8, 9, 1922) in being of nearly uniform width throughout, that is not showing a steady increase in width toward the final end, and by not having the distinct angular development of the chambers at the periphery. *Bolivina pulchella* (d'Orbigny) var. *primitiva* Cushman (Florida

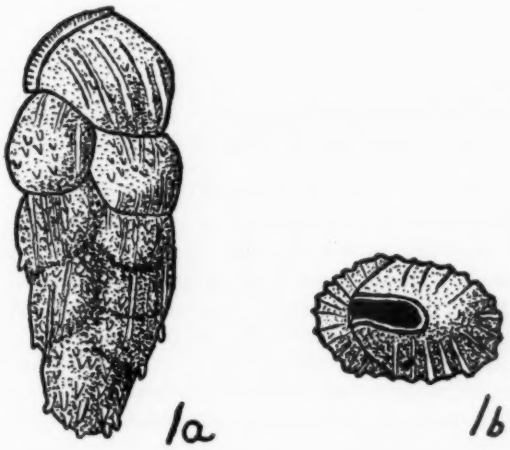


FIG. 1

St. Geol. Survey Bull. 4: 47, pl. 8, figs. 12 a, b. 1930) differs from *Bolivina beaufortana* in being practically free of spines.

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THE EFFECTS OF ENDOCRINES ON THE DEVELOPMENTAL RATES OF FLESH FLIES

By E. C. Hester and Bert Cunningham

Anatomical and embryological studies of invertebrates fail to show any organs, with the possible exception of the sex glands, of an endocrinal nature. If, therefore, there is any hormonal substance produced in invertebrates it must be secreted by tissues which are not recognized histologically as differentiated for this purpose.

The fact that endocrine organs as such are not to be found in invertebrates has led many to assume that endocrines would have little or no effect, as indicated by the usual physiological action, when applied to the invertebrates. It was to test this hypothesis that the following experiments were devised and conducted.

Because of their well known effects in vertebrates and because of the ease of procuring fresh glandular material, the thyroid and anterior pituitary were chosen as sources of the endocrines to be tested. Both of these organs produce substances related to growth, metamorphosis, and sexual maturity and should therefore produce significant changes in these processes if they have any effect, whatsoever, on invertebrates. Furthermore it has been shown for vertebrates that thyroid, when administered by feeding, produces as definite physiological effects as when the hormone is injected, although it takes a larger dosage to produce comparable results. While evidence that oral administration of pituitary is effectual is not so extensive, there are a number of experiments reported in the literature where oral administration has been effective.

Flesh flies appear to meet most fully the requirements for the invertebrate experimental animals since they are carnivorous both as larvae and adults. That they may thrive well on endocrine gland substance is evidenced by the fact that stock colonies are commercially raised on fresh thymus. They furthermore have the advantage of having short life cycles (about fifteen days) which may be further shortened or lengthened by controlling the temperature. *Phormia regina* was selected as the test animal.

The stock colony of *P. regina* was secured from the Lederle Laboratories, frozen thyroids from Swift and Co., anterior pituitaries from the

Wilson Laboratories, and ground meat (two-thirds beef, one-third pork) from local markets. Some of the studies were made at room temperatures which were more or less variable, ranging from 22° to 30°C., while others were made at temperatures which were controlled at or below 20°C. by refrigeration. The humidity was not kept constant but all the animals in any series were exposed to the same atmospheric conditions.

The flies were allowed to oviposit on flesh and when the eggs hatched the larvae were transferred to the beef or glandular tissue. When pupation had taken place the puparia were transferred to new containers where they were kept until the adults emerged. Upon emergence the adults were fed beef or gland, sugar and water, and were given opportunity, daily, to lay eggs upon fresh meat.

In this study three fundamental questions have been considered: (1) What effect, if any, does thyroid feeding have on the rate of development (a) at ordinary temperatures, and (b) at reduced temperatures? (2) Is there any cumulative effect transmitted from one generation to another? (3) What effect, if any, does anterior pituitary feeding have on the rate of development?

The data bearing on these points are assembled in Tables 1–5. We shall not attempt to make a complete analysis of the data, but we wish to point out what we think to be some of the more significant findings.

Feeding thyroid at room temperatures seemed to have little if any effect upon the time spent in the larval or pupal stage (see Table 2). The results may be summarized as follows:

	LARVAL LIFE				PUPAL LIFE					
	4 days		5 days		4 days		5 days		6 days	
	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Beef	872	56	667	43	718	54	524	40	69	5
Thyroid	882	55	719	44	734	55	562	42	37	2.5

These results do not agree with the findings of Kunkel (2), but he was working with another species. Nor do they fully agree with the findings of Brannon (1), who reported that the pupal life was shortened. This difference from our work may be due to the extremely low temperature (10°C.) which he maintained throughout his experiment. Our results do agree with Brannon in that we found no appreciable

TABLE 1

The effects of feeding thyroid on the length of larval life in days

SERIES	MEDIUM	NUMBER OF ANIMALS USED IN EACH SERIES	6 DAYS		7 DAYS		8 DAYS		9 DAYS		TOTAL NUMBER PUPATING	
			Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
I	Beef	100	35	35	58	58	5	5	.....	.....	98	98
I	Thyroid	400	46	11	239	60	8	.2	.....	.....	293	71
II	Beef	100	.....	.....	21	21	6	6	.....	.....	27	27
II	Thyroid	100	.....	.....	7	7	15	15	6	6	28	28
III	Beef	100	78	78	10	10	.....	.....	.....	.....	88	88
III	Thyroid	500	182	32	162	32	35	7	.....	.....	379	76
IV	Beef	100	27	27	54	54	12	12	.....	.....	93	93
IV	Thyroid	300	.....	.....	.....	.....	108	36	155	51	263	87
V	Beef	100	.....	.....	.....	.....	48	48	43	43	91	91
V	Thyroid	1,000	14	14	734	73	28	2.8	.....	.....	776	76
VI	Beef	100	31	31	13	13	.....	.....	.....	.....	43	43
VI	Thyroid	400	28	7	197	49	.....	.....	.....	.....	225	56
VII	Beef	100	9	9	38	38	.....	.....	.....	.....	47	47
VII	Thyroid	500	8	2	271	64	.....	.....	.....	.....	279	55
VIII	Beef	100	20	20	50	50	12	12	.....	.....	82	82
VIII	Thyroid	500	318	64	76	15	.....	.....	.....	.....	394	79
IX	Beef	100	.....	.....	20	20	3	3	.....	.....	23	23
IX	Thyroid	500	.....	.....	96	19	51	10	.....	.....	147	29
Total beef		900	200	22	264	29	86	9	43	5	593	66
Total thyroid		4,200	569	13	1,845	43	245	7	161	5	2,820	67
Grand total		5,100	769		2,109		331		204		3,413	

The effects of feeding thyroid on the length of pupal life in days

SERIES	MEDIUM	4 DAYS		5 DAYS		6 DAYS		7 DAYS		8 DAYS		TOTAL NUMBER OF PUPAE EMERGING		NUMBER OF LARVAE THAT BECAME ADULTS	AGE	
		Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent		4	5
I	Beef	.....	.....	.....	.....	5	5	70	70	1	1	76	76	77		X
I	Thyroid	.....	.....	.....	.....	.....	8	196	67	4	1.3	271	76	67	X	
II	Beef	2	8	10	37	.....	.....	.....	.....	.....	.....	12	47	12		X
II	Thyroid	.....	.....	1	3	7	25	5	17	.....	.....	13	46	13	X	
III	Beef	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....		
III	Thyroid	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....		
IV	Beef	.....	.....	.....	.....	4	4	63	70	13	14	80	89	80		X
IV	Thyroid	10	4	49	19	14	7	8	3	4	1	85	34	28	X	
V	Beef	25	26	4	4	.....	.....	.....	.....	.....	.....	29	30	29		X
V	Thyroid	.....	.....	.....	.....	15	2	333	42	340	45	688	89	69	X	
VI	Beef	.....	.....	10	23	1	.2	2	.5	1	.2	14	34	14		X
VI	Thyroid	.....	.....	1	.4	33	10	45	20	44	20	123	40	30	X	
VII	Beef	.....	.....	11	23	17	36	3	6	.....	.....	31	59	31		X
VII	Thyroid	2	.7	2	.7	33	12	65	23	49	14	151	48	30	X	
VIII	Beef	.....	.....	.....	.....	4	5	63	76	13	16	80	97	80		X
VIII	Thyroid	.....	.....	.....	.....	37	10	303	80	24	6	364	96	73		X
IX	Beef	.....	.....	5	22	5	22	7	30	.....	.....	17	74	17		X
IX	Thyroid	.....	.....	24	16	17	11	9	6	.....	.....	50	34	10		X
Total beef.....		27	4.5	40	7	36	6	205	34	29	5	339	55			
Total thyroid....		12	.42	77	2.4	177	6	959	34	465	16	1,690	60			
Grand total.....		39	.....	117	.....	213	.....	1,164	.....	494	.....	2,029	.....			

The nine series represent nine completely separate and independent experiments. Each series consisted of a beef control and one or more groups of thyroid fed animals. Each group within the series consisted of 100 newly hatched larvae which were transferred either to the beef or thyroid. Usually more than one group of thyroid fed animal was placed in a series. The larval life in days is the time intervening between hatching and pupation. The pupal life in days is the time transpiring between pupation and emergence. The column "Age" indicates the time required in days after emergence before oviposition began. Temperature 20°C.

TABLE 2

The effects of feeding thyroid to successive generations, at room temperatures, on the length of larval and pupal life

GENERATION	MEDIUM	LARVAL LIFE						PUPAL LIFE								PER CENT OF LARVAE THAT BECAME ADULTS	AGE	
		4 days		5 days		Total		4 days		5 days		6 days		Total				
		Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent		4	5
I	Beef	19	19	38	38	57	57	15	15	30	30	.....	.....	45	45	79		X
I	Thyroid	10	10	40	40	50	50	14	14	32	32	.....	.....	46	46	82	X	
II	Beef	21	21	50	50	71	71	4	4	63	63	13	13	80	80	88		X
II	Thyroid	76	76	24	24	100	100	2	2	98	98	.....	.....	100	.....	.....	X	
III	Beef	68	68	24	24	92	92	30	30	53	53	.....	.....	88	88	95		X
III	Thyroid	65	65	30	30	95	95	16	16	61	61	.....	.....	77	77	79	X	
IV	Beef	28	28	7	7	35	35	5	5	20	20	4	4	29	29	83		X
IV	Thyroid	24	24	7	7	31	31	12	12	8	8	3	3	23	23	74	X	
V	Beef	30	30	62	62	92	92	5	5	70	70	.....	.....	75	75	81		X
V	Thyroid	34	34	60	60	94	94	6	6	61	61	.....	.....	67	67	71	X	
VI	Beef	76	76	12	12	88	88	40	40	15	15	6	6	61	61	69		X
VI	Thyroid	36	36	52	52	88	88	20	20	35	35	7	7	62	62	67	X	
VII	Beef	40	40	43	43	83	83	24	24	5	5	.....	.....	29	29	35		X
VII	Thyroid	38	38	30	30	68	68	20	20	25	25	4	4	49	49	72	X	
VIII	Beef	30	30	12	12	42	42	10	10	1	1	3	3	14	14	33		X
VIII	Thyroid	8	8	54	54	62	62	31	31	16	16	.....	.....	47	47	76	X	
IX	Beef	27	27	62	62	89	89	3	3	60	60	13	13	76	76	85		X
IX	Thyroid	14	14	30	30	44	44	2	2	13	13	17	17	32	32	73	X	
X	Beef	31	31	12	12	43	43	18	18	12	12	.....	.....	30	30	70		X
X	Thyroid	30	30	13	13	43	43	5	5	28	28	.....	.....	33	33	76	X	
XI	Beef	42	42	4	4	46	46	38	38	8	8	.....	.....	46	46	100	X	
XI	Thyroid	28	28	30	30	58	58	37	37	18	18	2	2	57	57	98	X	

XII	Beef	42	42	4	4	46	46	38	38	8	8	.....	.....	46	46	88		X
XII	Thyroid	35	35	30	30	65	65	40	40	18	18	.....	.....	58	58	86	X	
XIII	Beef	60	60	30	30	90	90	55	55	30	30	.....	.....	85	85	94		X
XIII	Thyroid	40	40	25	25	65	65	33	33	17	17	.....	.....	50	50	79	X	
XIV	Beef	58	58	16	16	74	74	60	60	7	7	.....	.....	67	67	90		X
XIV	Thyroid	63	63	17	17	80	80	58	58	13	13	.....	.....	71	71	89	X	
XV	Beef	40	40	37	37	77	77	50	50	17	17	.....	.....	67	67	87		X
XV	Thyroid	76	76	3	3	79	79	40	40	9	9	1	1	50	50	63	X	
XVI	Beef	18	18	40	40	58	58	23	23	18	18	.....	.....	41	41	71		X
XVI	Thyroid	62	62	17	17	79	79	55	55	17	17	.....	.....	72	72	91	X	
XVII	Beef	62	62	30	30	92	92	40	40	31	31	1	1	72	72	79		X
XVII	Thyroid	60	60	25	25	85	85	58	58	20	20	.....	.....	78	78	91	X	
XVIII	Beef	18	18	50	50	68	68	43	43	19	19	.....	.....	62	62	91		X
XVIII	Thyroid	36	36	50	50	86	86	61	61	17	17	1	1	79	79	91	X	
XIX	Beef	24	24	28	28	52	52	35	35	7	7	.....	.....	42	42	80		X
XIX	Thyroid	18	18	50	50	68	68	61	61	3	3	1	1	65	65	95	X	
XX	Beef	53	53	11	11	64	64	54	54	7	7	.....	.....	61	61	92		X
XX	Thyroid	28	28	36	36	64	64	40	40	9	9	1	1	50	50	79	X	
XXI	Beef	40	40	42	42	82	82	50	50	29	29	.....	.....	79	79	96		X
XXI	Thyroid	36	36	28	28	64	64	40	40	21	21	.....	.....	61	61	92	X	
XXII	Beef	11	11	20	20	31	31	26	26	5	5	.....	.....	31	31	100		X
XXII	Thyroid	32	32	41	41	73	73	60	60	5	5	.....	.....	65	65	89		
XXIII	Beef	43	43	30	30	73	73	50	50	13	13	.....	.....	63	63	86		X
XXIII	Thyroid	33	33	27	27	60	60	43	43	18	18	.....	.....	61	61	98		
Total beef.....		872	.....	667	.....	1,539	.....	718	.....	524	.....	69	.....	1,311	.....	.....		
Total thyroid.....		882	.....	719	.....	1,601	.....	734	.....	562	.....	37	.....	1,333	.....	.....		

effect on the length of larval life at room temperatures. It is to be remembered that Brannon used a different species from that which Kunkel used, and the one which we used. In our experiments the time between emergence and oviposition was consistently shortened.

Thyroid feeding at a controlled temperature of 20°C. increased the length of time, as compared to meat, spent in both the larval and pupal forms (see Table 1). The hastening of sexual maturity was also evident under these conditions.

That the thyroid tissue serves as a good basic food for these flies was evidenced by the comparative number of larvae pupating, the number

TABLE 3

The effects of feeding thyroid on oviposition in successive generations

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Number of thyroid adults depositing eggs	23	47	40	11	16	9	16	38	8	9	13	16	20	20	30	16	16	22	17	6	8	0	0
Number of thyroid adults depositing eggs after beef feeding																					23	19	0
Number of beef adults laying eggs	18	40	32	13	50	36	6	3	20	7	16	21	40	23	30	16	32	20	11	26	32	16	19
Per cent of thyroid adults depositing eggs	50	47	52	49	23	60	31	17	25	27	30	30	40	30	60	22	21	20	22	12	16	30	0
Per cent of beef adults depositing eggs	40	50	40	49	66	43	21	22	25	23	39	50	47	29	45	40	45	44	24	40	40	51	30

of pupae emerging and the number of adults laying eggs (see Tables 1 and 2). The failure of thyroid to affect the pupa or larva at room temperatures, and its later striking effect on the adult is disconcerting.

The data relative to the cumulative effects are shown in Table 2. Through twenty-three generations there was no appreciable change, as compared to controls, in the length of time spent as larvae or pupae. While flies produced from thyroid-fed larvae in each generation up to the 21st, became sexually mature earlier than the controls, there was no evidence of any cumulative effect in further shortening the period.

Although there seems to be no relation of the thyroid feeding to the number of egg masses produced in the earlier generations, some influence

TABLE 4

The effects of feeding anterior pituitary at temperatures from 11°C. to 20°C. on the length of larval life in days

SERIES	MEDIUM	TEMPERATURE	12	13	14	15	16	17	18	19	20	21	22	23	24
1	Beef	20	14		14		3								
1	Pituitary	20	15	2	5										
2	Beef	17				1	15	5							
2	Pituitary A	17			13	10	5								
2	Pituitary B	17			15	15									
3	Beef	15					3	1	5	4	3				
3	Pituitary A	15			3	3	7								
3	Pituitary B	15			3	8	7	3							
4	Beef	13		2	3			3	11		10				
4	Pituitary A	13				1		4	11						
4	Pituitary B	13		3				13							
4	Pituitary C	13			7	3		8	1						
4	Pituitary D	13		1		2			13						
4	Pituitary E	13				4		10							
5	Beef	13				1	3			1	2	1	2	20	
5	Pituitary A	13					1				5	2	7		
5	Pituitary B	13				4	9	10	1	1	2				
5	Pituitary C	13						5	2	1	12	5			
5	Pituitary D	13				10	10	6	4	3					
5	Pituitary E	13					2	2		2	4	15			
5	Pituitary F	13						1		1	13	10	3		
5	Pituitary G	13						3	14	6	2				
5	Pituitary H	13					2		2			10	12		
6	Beef									16					
6	Pituitary A		5			3									
6	Pituitary B					2		7	9	17					
6	Pituitary C						10	4		3					
7	Beef	15					1	1	1	2	4	4	3	8	
7	Pituitary A	15				6	7	6		4	4	1			
7	Pituitary B	15			4	6	6		3	4	1				
7	Pituitary C	15			1	4	7	6		2	1				
8	Beef	16			3	6	11	7	9	9					
8	Pituitary A	16		1	15	5	10	3							
8	Pituitary B	16					4	18	3						
8	Pituitary C	16				2	4	1							
8	Pituitary D	16				2	10	13							
8	Pituitary E	16		1	17	11									
9	Beef	13								1	10	12			
9	Pituitary A	13			8	4		16	1						
9	Pituitary B	13						1	6	5		3			
9	Pituitary C	13			1			3		6					

TABLE 4—*Continued*

SERIES	MEDIUM	TEMPERATURE	12	13	14	15	16	17	18	19	20	21	22	23	24
9	Pituitary D	13	...	...	1	...	...	1	...	...	1	...	...	...	...
9	Pituitary E	13	...	6	12	6	...	6	7	...	...	...	...	...	...
10	Beef	14	...	...	...	...	...	...	...	...	9	4	...	3	...
10	Pituitary	14	...	...	...	...	...	2	6	15	12	3	...	1	...
11	Beef	14	...	...	...	...	...	...	...	1	4	4	2	8	8
11	Pituitary A	14	...	...	...	...	...	...	...	...	...	5	1	10	...
11	Pituitary B	14	...	...	...	...	...	...	2	9	12	...	...	...	...
11	Pituitary C	14	...	...	...	...	...	...	...	...	...	...	5	2	...
11	Pituitary D	14	...	...	...	...	...	5	6	12	2	...	...	...	...
11	Pituitary E	14	...	...	...	...	...	...	2	6	...	2	3	2	...
11	Pituitary F	14	...	...	...	...	...	...	...	...	2	6	5	...	...
11	Pituitary G	14	...	...	...	...	...	1	7	3	11	...	...	...	...
11	Pituitary H	14	...	...	...	...	...	...	...	...	4	10	9	5	...

The effects of feeding anterior pituitary at temperatures from 11°C. to 20°C. on the length of pupal life in days

SERIES	MEDIUM	TEMPERATURE	13	14	15	16	17	18	19	20	21	22	23	24	25
1	Beef	20	...	...	...	...	11	...	...	...	...	...	...	...	...
1	Pituitary	20	...	3	7	6	3	...	...	...	...	...	...	...	...
2	Beef	11	...	...	...	...	...	...	...	...	...	...	13	7	
2	Pituitary A	11	...	...	...	...	...	...	4	10	5	2	1	...	...
2	Pituitary B	11	...	...	...	...	...	...	...	...	4	5	16	6	...
3	Beef		...	...	...	...	...	...	...	...	...	...	2	10	...
3	Pituitary A		...	...	...	...	...	...	...	4	...	5	3	...	...
3	Pituitary B		...	...	...	...	...	...	...	2	2	5	...	...	...
4	Beef	13	...	...	...	...	...	...	2	2	13	13	...	...	...
4	Pituitary A	13	...	...	...	...	...	...	...	3	9	...	...	...	...
4	Pituitary B	13	...	...	...	...	1	...	...	8	6	...	...	...	...
4	Pituitary C	13	...	...	...	...	...	...	...	1	5	...	...	...	...
4	Pituitary D	13	...	...	...	...	...	...	...	5	4	2	...	...	...
4	Pituitary E	13	...	...	...	...	4	...	...	...	1	...	...	...	...
5	Beef		...	...	...	...	1	2	1	...	2	5	2	...	...
5	Pituitary A		...	...	...	...	...	...	8	10	3	...	...	...	...
5	Pituitary B		...	...	...	...	2	5	12	2	...	2	...	...	...
5	Pituitary C		...	...	...	...	...	...	...	1	7	3	...	...	...
5	Pituitary D		...	...	...	...	12	5	3	...	...	...	...	...	...
5	Pituitary E		...	...	...	...	...	1	3	6	3	7	...	...	...
5	Pituitary F		...	...	...	...	...	...	...	1	2	15	...	...	...
5	Pituitary G		...	...	...	...	...	...	...	10	1	...	2	...	...

TABLE 4—*Concluded*

SERIES	MEDIUM	TEMPERATURE	13	14	15	16	17	18	19	20	21	22	23	24	25
5	Pituitary H		...	...	...	...	...	...	2	1	5	10	...	...	...
6	Beef		...	...	...	12	...	...	...	...	...	...	...	...	...
6	Pituitary A		...	...	5	1	...	...	...	...	...	...	...	...	...
6	Pituitary B		14	...	...	9	...	...	...	...	...	...	...	...	...
6	Pituitary C		...	7	2	2	...	...	...	...	...	...	...	...	...
7	Beef		...	...	...	...	...	...	...	3	...	2	2	2	3
7	Pituitary A		...	...	...	...	...	...	...	15	2	4	2	...	...
7	Pituitary B		...	...	...	...	...	...	...	5	1	5	3	...	...
7	Pituitary C		...	...	...	...	...	...	...	...	1	2	2	3	...
8	Beef		...	...	...	...	...	...	...	13	11	...	5	...	...
8	Pituitary A		...	...	...	...	...	...	3	3	11	...	...	...	...
8	Pituitary B		...	...	..	...	...	...	6	12	...	...	...	...	...
8	Pituitary C		...	...	...	...	...	...	1	12	1	5	...	...	...
9	Beef	11	...	...	...	...	...	...	...	...	...	...	...	...	15
9	Pituitary A	11	...	...	...	...	...	...	...	...	...	...	9	9	1
9	Pituitary B	11	...	...	...	...	...	...	...	...	...	...	2	1	8
9	Pituitary C	11	...	...	...	...	...	...	...	...	...	...	2	1	3
9	Pituitary D	11	...	...	...	...	...	...	...	...	9	4	3	...	...
9	Pituitary E	11	...	...	...	...	...	...	...	...	10	4	6	...	...
10	Beef		...	...	...	...	...	...	...	...	...	...	1	1	5
10	Pituitary		...	...	...	...	...	...	...	3	8	8	2	...	...
11	Beef		...	...	1	...	5	...	...	5	...	...	...	...	...
11	Pituitary A		...	...	...	...	1	2	4	...	...	...	...	...	...
11	Pituitary B		...	...	9	...	14	...	...	...	...	...	...	...	...
11	Pituitary C		...	...	...	...	5	7	...	1	...	...	...	...	...
11	Pituitary D		...	...	...	10	6	4	...	...	...	...	...	...	...
11	Pituitary E		...	...	...	...	4	3	...	...	...	...	...	...	...
11	Pituitary F		...	...	1	...	6	2	1	...	...	...	...	...	...
11	Pituitary G		...	...	15	7	2	2	3	...	...	...	...	...	...
11	Pituitary H		...	...	1	...	11	1	...	...	...	...	...	...	...

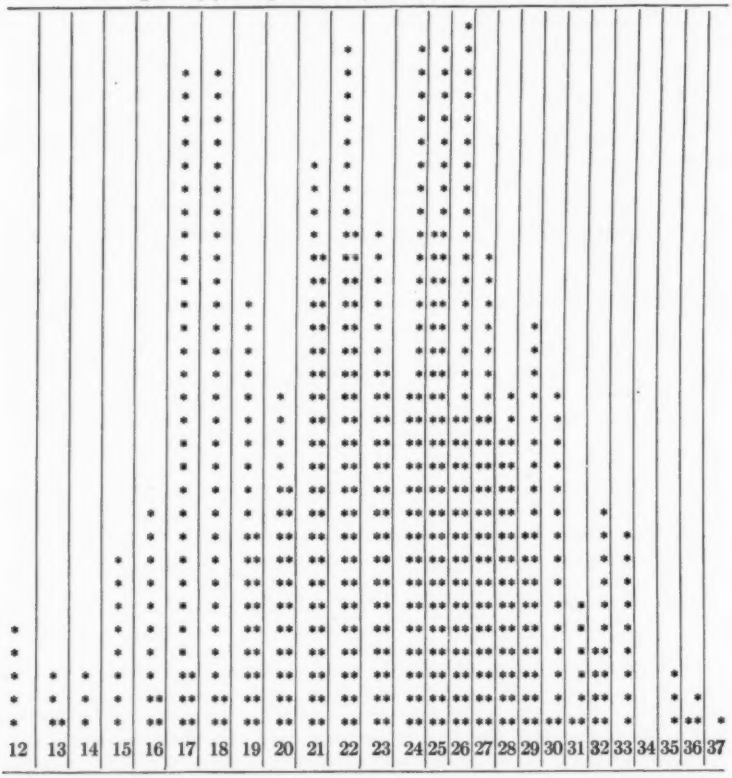
These experiments were set up in the same manner as those shown in table 1. Each series consisted of a control (beef fed) and one or more groups of pituitary fed animals. Each group at its beginning consisted of 100 newly hatched larvae. Where the temperature remained fairly constant during the experiments they have been set down, but where they were variable to any great degree the temperatures have been omitted from the table. In such cases however the temperature rarely rose above 20°C.

seems to be evident after the 15th generation (see Table 3). This condition became critical in the 21st generation where there was a marked reduction in the number of "thyroid-fed flies" that oviposited. When, however, these flies were allowed to feed on beef many of them deposited

eggs. In the 22nd generation none of the thyroid fed adults laid until they were fed beef, and in the 23rd generation the experimental adults failed to lay even after having been fed beef. Why there should be such

TABLE 5

The effects of feeding anterior pituitary on the size of puparia



The puparia are distributed according to size, each star representing an individual. Those in the column over the first figure of a given volume are controls—and those over the second figure are pituitary fed.

a sudden appearance of sterility in the thyroid fed flies after so many fertile generations is not clear.

The effects of feeding anterior pituitary were studied only at lowered

temperatures, ranging from 11° to 20°C., where rather striking results were secured. The larval life was shortened as was also the pupal life (see Table 4). The puparia formed were also larger than the controls (see Table 5). These results do not agree with those of Patterson (3) who, working with a larviparous flesh fly, was unable to find any effect of pituitary on the growth of the larvae or the size of puparia. His experiments involved at least 20 different set-ups including controls, and less than 200 individuals were considered in the entire study. Furthermore he used "slightly decomposing" pituitary substances as media.

Since the time required by our experimental animal for reaching sexual maturity after emergence did not seem to be appreciably different from the controls, the data have not been tabulated here.

The growth effects of pituitary feeding are not surprising since a growth factor is thought to be present in the pituitary. In this case however, the hormone must work directly upon the tissues. The failure of pituitary feeding to hasten sexual maturity is surprising since the gland normally contains a gonad stimulating hormone, and it was shown herein that the *Phormia regina* gonad can be stimulated by thyroid feeding.

SUMMARY

At room temperatures the length of larval and pupal life were not modified by thyroid feeding as compared to beef feeding, but the time between emergence and oviposition was shortened.

At a temperature of 20°C. both larval and pupal life was lengthened as compared to the controls. Under these conditions also the time required for reaching sexual maturity was shortened.

At temperatures ranging from 11° to 20°C. pituitary feeding shortened the length of both larval and pupal life as compared to controls. However no difference as to the time required to reach sexual maturity after emergence was observed between pituitary and beef fed animals.

There were no cumulative effects observed during some twenty-three generations but sterility appeared rather suddenly in the 21st and 22nd generations of the thyroid fed animals.

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THE PHOTOCHEMICAL DECOMPOSITION OF CARBON DISULFIDE

By P. M. Nicholes, N. L. Simmons, and H. D. Crockford

O. Loew (5) states that when carbon disulfide is exposed to sunlight a deposit of carbon trihemisulfide, C_2S_3, is formed on the walls of the container. Th. Sidot (7) states that carbon monosulfide, CS, is formed upon exposure to sunlight. The product is a red powder of approximately 1.65 specific gravity. Dewar and Jones (2) considered the product of Sidot to be a polymer of the monosulfide. Doran and Gilliam (3) studied the photochemical decomposition of carbon disulfide in carbon tetrachloride solution and found a product with properties similar to the above. They considered the product to be $(CS)_x$.

The absorption spectrum of carbon disulfide in the ultra violet has been studied by Bruhat and Pauthenier (1), Wilson (8), and Haverlock (4). From a consideration of the work of these investigators it can be concluded that carbon disulfide absorbs all wave lengths between 1900 and 3600 Å with the exception of a short range between 2700 and 2900 Å. The maximum absorption is found at approximately 3200 Å.

In this paper are given the results of a study of the decomposition of liquid carbon disulfide upon exposure to ultra violet light. Three sulfides of carbon were obtained besides elemental sulfur. These three sulfides were: a red-brown powder of probable formula $(CS)_x$, a red liquid of formula C_3S_2, and a brown solid which is probably a polymer of the latter.

METHODS OF ILLUMINATION

Mercury arc lamps made of Pyrex glass and cooled by water jackets were used as the principal sources of illumination. The use of Pyrex glass of course fixed the short wave decomposition limit at 2900 Å. The carbon disulfide was contained in Pyrex tubes of approximately three inches diameter. These were either sealed off or closed with tight-fitting stoppers. Experiments proved that small quantities of air in the tubes had no effect on the results. Tests were also made with a quartz mercury vapor lamp emitting monochromatic radiation of 2537 Å.

The carbon disulfide in these cases was contained in quartz vessels. Similar results were obtained with both types of lamps.

In order to test the long wave length decomposition limit certain samples were illuminated with light filtered through a Corning No. 586 glass filter. This, in conjunction with the lamp used, produced light of approximately 3660 Å wave length. Other samples were illuminated in tubes made of soft glass. In both cases little, if any, decomposition took place. These experiments fix the long wave length limit at approximately 3600 Å which is in agreement with the conclusions drawn from the absorption spectra data.

It is thus seen that the results given in this paper are due to the action of light between the limits of 2900 and 3600 Å.

PRODUCTS OBTAINED

As stated the products obtained were as follows: a red-brown precipitate of probable formula $(CS)_x$; a dark red liquid, carbon ditritasulfide, C_3S_2; a brownish-yellow film which is probably a polymer of the ditritasulfide; and free sulfur. These products were formed in very small quantities so that microchemical methods of analysis had to be used, in most cases the individual samples being approximately ten milligrams in weight. The analyses are accurate to $\pm$ 1 percent.

The first appearance of solid material when carbon disulfide was exposed to the radiations was the formation of minute particles, almost colloidal in nature, which upon standing for some hours after illumination formed a red-brown precipitate. This was recovered from the liquid by filtration through crucibles with sintered glass bottoms. The precipitate was carefully washed with hot carbon disulfide, ether, and acetone. It was tasteless; odorless; apparently insoluble in the ordinary organic solvents, dilute sulphuric acid, dilute nitric acid, and sodium hydroxide solution. It was slightly soluble in cold, concentrated nitric acid and dissolved readily in the hot acid to produce a red solution. It dissolved in concentrated sulfuric acid, the solution changing to a purplish-brown color when heated. Dilution with water in both cases produced a reprecipitation. The substance was somewhat soluble in pyridene but no suitable solvent was found for purposes of purification. An attempt to obtain the melting point was unsuccessful as decomposition with the formation of carbon and sulfur took place over a range from 220 to 240°C.

The powder was analyzed for sulfur and carbon according to the methods given by Pregl, "Quantitative Microanalysis." For accurate

details the reader is referred to this book. Briefly the process for sulfur was as follows. The sample, previously dried for several days at 125°, was weighed into a porcelain boat which was placed in a combustion tube, approximately 50 cm. in length, one end of which was filled for a distance of 20 cm. with glass beads, the surfaces of which were covered with 30% hydrogen peroxide solution. Between the beads and the sample were located two pieces of platinum foil catalyst. Carefully purified oxygen was passed over the sample with proper heating. The resulting sulfur dioxide was catalyzed to sulfur trioxide by the platinum catalyst. This trioxide was in turn converted by the hydrogen peroxide to sulfo-mono-peracid, H_2SO_5, which after removal was titrated, methyl orange being employed as the indicator. For the carbon a quartz combustion tube was used, the resulting carbon dioxide being absorbed in soda lime after the oxides of sulfur were removed by bubbling through chromic acid. Combination of the sulfur and carbon analyses were unsuccessful. It was found in both cases that complete combustion was impossible, a residue, making up about 15% of the total, remaining after combustion. The part which reacted gave for carbon 26.3% and for sulfur 73.7%. It is seen that this analysis corresponds closely to the composition CS, which formula gives a theoretical sulfur value of 72.7%. This would indicate an incomplete removal of the free sulfur from the powder.

As the carbon monosulfide described by Mellor (6) is a gas in the unpolymerized state the product obtained by us is undoubtedly a polymer. As described by Mellor such a polymer has been prepared by several investigators, the properties being very similar to those of the powder. For purposes of comparison $(CS)_x$ was prepared by us according to the method of Dewar and Jones (2). This method employs the reaction between thiophosgene and nickel carbonyl. The product so obtained was identical with the brown powder both in respect to properties and analysis. The same residue was found on combustion.

The red liquid was soluble in carbon disulfide and was obtained by evaporating the filtrate from the solid products under reduced pressure. The resulting dark red liquid contained some dissolved sulfur which was separated by dissolving the red liquid in ethyl alcohol. However this method is only partially successful. To prevent polymerization the liquid was stored in acetone from which it was recovered by evaporation of the solvent. The liquid was analyzed for carbon and sulfur according to the methods employed for the $(CS)_x$. The analysis

showed: carbon, 34%; sulfur, 66%. The liquid is characterized by a strong, penetrating odor and low vapor pressure. It is soluble in most organic solvents imparting to the solutions a red-brown color. When heated in a small test tube a black mass results with the formation of free sulfur and the evolution of a gas with a mercaptan-like odor. An attempt to freeze the liquid was unsuccessful. It became very viscous and although temperatures as low as −20°C. were employed complete solidification was never obtained. The liquid shows a decided tendency to polymerize in the free state and in carbon disulfide solutions. A semi-hard black mass results. Moreover on the sides of the container a film is formed similar in appearance to that found in the original containers employed by us for exposing the carbon disulfide to the radiations.

The properties agree very well with those of carbon ditritasulfide, C_3S_2, described by Mellor (6). This has been prepared and studied by several investigators as stated in the above reference. However, while our product had a penetrating, disagreeable odor it did not have the destructive and harmful effect on the mucous membranes of the nose as stated by Mellor. Nor were we able to secure a definite melting point. Mellor states that solidification should take place at −.5°C. The sulfur content of carbon ditritasulfide is 64%. The sulfur content of the red liquid is somewhat higher than this. In fact the analysis conforms more closely to C_4S_3 rather than C_3S_2. However due to the difficulty of removing the last traces of free sulfur a high sulfur percentage is not hard to explain.

After about eight hours exposure a brown film formed on the side of the reaction vessel nearest the source of illumination. By turning the tube a uniform deposit could be obtained. Once formed this film served to effectively prevent further penetration of the light. The film deposited was easily displaced by the addition of water with subsequent shaking. The material was in the form of thin, semitransparent flakes of a brownish-yellow color. The method of separation from the liquid was essentially the same as that employed for the red powder. It was found impossible to secure this film free of the powder. The final product appeared amorphous under the microscope. There seemed to be no true melting point, decomposition taking place slightly above 200°C. with the formation of carbon and sulfur. From the standpoint of solubility the properties were similar to those of the red-brown powder, $(CS)_x$. The same action was found with the inorganic acids. Analysis for carbon and sulfur in the usual way showed 31.5% car-

bon and 68.5% sulfur. In view of this analysis and the great similarity of this film to the product obtained from polymerization of the C_3S_2 it was concluded that this film was a polymer of the carbon ditritasulfide. The high sulfur percentage was no doubt due to the fact that the film could not be completely purified from the brown powder. As with the $(CS)_x$ complete combustion could not be secured, a residue always remaining. It should be added that there seems to be no record in the chemical literature of a polymer of C_3S_2 of this type.

SUMMARY

1. The photochemical decomposition of carbon disulfide has been studied using the full radiation from quartz and mercury vapor lamps.

2. Besides elemental sulfur three sulfides of carbon have been obtained as products: a red powder, $(CS)_x$; a red liquid, C_3S_2; and a yellowish-brown solid, $(C_3S_2)_x$.

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THE STRUCTURE AND DEVELOPMENT OF THE SEED OF PAULOWNIA TOMENTOSA STEUD.*

By VERA MILLSAPS

PLATES 4–6

HISTORICAL INTRODUCTION

The ovules of the Scrophulariaceae have been studied by various workers since the time of Hofmeister. In his classic work of 1849 Hofmeister (11) stated on the basis of his examination of a large number of species that the embryo developed from a fertilized egg, and expressed the belief that this phenomenon was common in all phanerogams. It is interesting to note that he used two genera of the Scrophulariaceae, *Lathraea squamaria* and *Pedicularis sylvatica* for further investigation of this subject in 1851, and proved unmistakably that the embryo was formed as the result of a fertilized egg (12). These facts undermined the pollen-tube theory of Schleiden who had maintained in 1835 that the embryo developed from the tip of the pollen tube (8, 18). Hofmeister's researches, published in 1855, were so decisive that they discredited Schleiden's contention for all time (13).

Pedicularis sylvatica was the subject of considerable controversy in 1855 between Deecke (9) and Schacht (17) on the one hand and Hofmeister (13), von Mohl (16), and Tulasne (23) on the other. Deecke reinvestigated *Pedicularis* in 1855 and claimed that Hofmeister was wrong in saying that the embryo did not develop from the tip of the pollen tube (9). Schacht agreed with Deecke's statements. Hofmeister cleared up the whole matter by showing that what Deecke had really seen was the proembryo (13).

The next work of any importance on the Scrophulariaceae was done by Chatin in 1874 when he investigated the development of the ovule and the seed in several genera, putting special emphasis upon *Veronica* (5). In 1879 Vesque investigated the embryo sac in a number of families, including several members of the Scrophulariaceae (25). Even

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at this time, twenty-four years after Hofmeister's decisive statement concerning embryo formation, Vesque still believed that Schleiden's theory was correct.

Three years later, in 1882, Bachmann (1) made an intensive study of the structure and development of the seed coat of a large and representative number of the Scrophulariaceae. He found three layers in the testa of the majority of species examined, the outer one usually being strengthened by a characteristic net thickening.

In 1899, Balicka-Iwanowski made a study of the embryo sac in a number of the Sympetalae, dealing especially with several genera of the Scrophulariaceae (2). This paper remains a classic in its field. This worker emphasized the question of nutrition in the embryo sac and believed that the haustoria could absorb food and conduct it to the embryo sac. She did not consider the tapetum as a protective covering, but as a layer of cells having a digestive and nutritive function.

In 1906, Schmid made a valuable contribution to our knowledge with reference to the Scrophulariaceae (20). He confined himself entirely to this family, discussing the formation of the embryo sac, fertilization, endosperm formation, and the development of the haustoria. He paid special attention to the development of the endosperm and arranged the genera which he studied into four groups according to their method of endosperm formation.

Verbascum, *Scrophularia*, and *Digitalis*, of his first group, form four superimposed primary endosperm cells of which the outer two form feeble haustoria while the inner two function as true endosperm.

The first endosperm cell in the members of the second group, consisting of *Linaria* and *Antirrhinum*, divides transversely. The micropylar cell thus formed develops the endosperm and a few of the endosperm cells at the micropylar end function as haustoria. The lower cell forms a tube-like haustorium in which the nucleus divides once though no cell wall is formed.

Alectorolophus and *Lathraea* form the third group. Here again the lower cell forms a haustorium. The micropylar haustoria are formed by two cells which arise from the micropylar end of the upper endosperm cells and become binucleate.

The fourth group, consisting of *Veronica*, *Euphrasia*, *Pedicularis*, *Melampyrum*, and *Tozzia*, is like the third except that the micropylar haustorium originates from one cell and has four nuclei.

It is Schmid's opinion that the endosperm characters should be considered in making a natural classification of the family.

A study of the genus *Pentstemon* was made by Krautter in 1908, in which he paid considerable attention to a comparative study of the seeds of the genus with regard to weight, size, number and structure of layers of the testa, and external appearance (14).

The next definite work was done on the Scrophulariaceae in 1915 by Margaret Michell who investigated the embryo sac and embryo of *Striga lutea*, a semi-parasitic member of this family which is common on maize in South Africa (16). In this species the endosperm is formed by cell division. A long binucleate haustorium penetrates the chalazal region while a few endosperm cells function as an inconspicuous micropylar haustorium. The proembryo has a long suspensor of three or four cells, the basal one of which forms tuberous haustoria. According to Miss Michell this is the only case of such haustoria recorded for the Scrophulariaceae. There is no definite tapetal layer.

Four years later, in 1919, Arthur T. Evans studied the embryo sac and embryo of *Pentstemon secundiflorus* (10). The 8-nucleate embryo sac in this species is decidedly club-shaped, much more so than any other known in the family. The chalazal end is usually long and narrow, and is surrounded by a tapetum. The endosperm nucleus divides immediately after its formation and free nuclei move down into the chalazal end, a narrow neck being left between. Wall formation begins and continues until the space is filled with cells. The proembryo is pushed down into this endosperm by unusual growth of the suspensor. Four endosperm cells which become binucleate form the chalazal haustorium. Two endosperm cells form the micropylar haustorium by pushing up through the narrow neck into the micropylar end of the sac. Their growth stops as soon as the embryo is pushed down between these cells into the endosperm. The whole micropylar region of the sac finally disappears due to the pressure of the increasing endosperm.

In the same year, 1919, F. M. Schertz investigated the embryo sac of *Scrophularia marylandica* (19). In this species the tapetal layer completely surrounds the embryo sac. Endosperm is formed by cell division, and the embryo sac is filled with cells before the egg divides. There are two well developed haustoria in the chalazal region and four small ones at the micropylar end of the sac.

A recent paper by Melville T. Cook on the development of the seed of *Linaria vulgaris* appeared in 1924 (7). In this species also the embryo sac is entirely surrounded by tapetum. The endosperm is of the cellular type, but there are no haustoria developed. Cook states that he found the majority, and in some cases all, of the seeds in an ovary without

embryos. Even in some cases where pollen tubes had entered sacs no embryos were formed. The endosperm develops in the usual way regardless of the presence or absence of an embryo.

The present paper deals with the structure and development of the seed of *Paulownia tomentosa* Steud., a plant belonging to the sub-family Antirrhinoideae of the Scrophulariaceae. A native of China, it was introduced into this country from Japan about 1834 as an ornamental tree. It has since escaped from cultivation and is now sparingly spontaneous from New York southward.

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MATERIAL AND METHODS

The material for this investigation of *Paulownia tomentosa* was collected from trees in Chapel Hill, N. C., during the years 1933 and 1934 except for a small amount that was collected from one tree in Statesville, N. C., during September, 1933. Floral buds begin to form during the first week in August for the next year's flowers at the time when the present year's fruit is maturing; hence collections had to be made throughout an entire year.

The material was killed in medium chromo-acetic solution, formalin acetic alcohol, and medium Flemming's fluid during the early part of the work. Later it was discovered that a combination of Carnoy's and Nawaschin's fixing fluids gave the best results and their use was adopted for the latter part of the work almost entirely. The material was put in Carnoy's fluid for 8–10 minutes and then allowed to stand in Nawaschin's fluid overnight.

Some difficulty was encountered in cutting the early stages of the bud due to the hardening of the tissues during dehydration with ethyl alcohol and xylol. This was overcome by the use of ethyl alcohol and n-butyl alcohol for dehydration (27). These were used entirely in all the later work with all stages.

Haidenhain's iron-alum haematoxylin, a combination of Delafield's

haematoxylin and erythrosin, and Flemming's triple stains were used. The most satisfactory results were obtained with Flemming's triple stain, or with safranin and gentian violet alone, on material that had been fixed with Carnoy's and Nawaschin's fluids. Feulgen's stain was used with good results for staining nuclei in germinated pollen tubes (21).

DEVELOPMENT OF THE MICROSPORANGIUM AND THE MALE GAMETOPHYTE

Floral buds begin to form about the first of August. Sections made from very young buds collected about August 17th show the beginning of the four lobes of the anther and the presence of two layers of cells just within the epidermis that are already differentiated as the primary parietal and primary sporogenous layers. Growth is rapid and a little later sections show two or three rows of parietal cells and several rows of sporogenous tissue. Figures 2 and 3 show a mass of young spore mother cells surrounded by a single row of tapetum.

Four rows of parietal cells is the usual number on the outer curves of the lobes, though there may be five toward the sides of the lobes. The innermost of these layers becomes the tapetum, the cells of which soon become more deeply staining and multinucleate (Fig. 3). The cells of these parietal layers tend to flatten somewhat, so that by the time the anther is mature its walls are much thinner than when first formed (Figs. 7, 16). There is no special differentiation of parietal tissue to facilitate dehiscence except that at the bottom of the groove separating the two lobes there are two thin lines in the wall, where the break occurs.

In sections of anthers collected September 12th practically all later stages were found. There are pollen mother cells well rounded off and separated from each other within pollen sacs completely lined with large binucleate tapetal cells; diad stages of the first reduction division showing late metaphase and telophase stages of nuclear activity; early and mature tetrad stages of microspores, accompanied by slightly less turgid tapetal cells; and also uninucleate spores lying free within the spore cavity. In some flowers uninucleate spores with recognizable thin spots in the exine were found as early as September 4th. By October 17th the tube nucleus and generative nucleus are present, but show no particular difference in size. The tube nucleus is definitely larger by November 9th, and the smaller generative nucleus is more deeply staining and enclosed by a lenticular cell embedded in the protoplasm of the spore. This is the condition when the pollen is shed some time in

April. Pollen grains sprouted in 5% sugar solution soon show the two nuclei in the tube (Fig. 15).

The pollen mother cell stage here occurs more than a month earlier than in *Salix* (3) and *Populus* (4), though in the latter sporogenous cells appear in July, or almost a month earlier than in *Paulownia*. Notwithstanding this early start, the winter is passed in the mother cell stage in those genera. In *Corylus* and *Alnus*, however, also reported by Chamberlain (4), fully formed spores with two nuclei are found in midwinter, as in *Paulownia*. It is probable that most trees and herbs that flower in the early spring develop their microsporangia before the end of the "growing season" and carry them through the winter in the mother cell stage (8). The large flower buds of *Paulownia*, a centimeter or more in diameter, the size being largely due to the very thick, brown, felt-like calyx, occur on terminal racemes in numbers ranging from 50 to 150 or more, and make a very conspicuous appearance throughout the fall and winter months.

DEVELOPMENT OF THE MACROSPORE AND THE EMBRYO SAC

The ovary of *Paulownia tomentosa* is of the bilocular scrophulariaceous type with the partition greatly swollen at the mid-point on the median line and forming in each locule a large almost hemispherical placenta which bears a great number of anatropous ovules. As many as 2000 seeds have been counted in a single average sized capsule (26). Longitudinal sections of the ovary supply a great number of ovules in each section for study.

The ovules begin to arise from the placenta about the same time that the sporogenous layer in the anther becomes well differentiated, forming little protuberances all over the surface. The archesporial cell is recognizable at an early stage before the integument arises by its larger size, larger nucleus, and different reaction to stains, all of which are characteristic of the family (20). This type of cell is found in collections as early as August 20th. It arises from a single hypodermal cell which, without further division, becomes the megaspore mother cell directly. No parietal cell is cut off, thus conforming to the general rule among investigated Sympetalae (8).

The young ovule grows rather rapidly and by September 12th the origin of the integument is discernible. It grows partly up about the single layered nucellus and remains in this condition until activity is resumed in the spring. The nucellus makes a rounded protuberance at the tip of the ovule, which is completely anatropous by the middle of October (Fig. 17).

During the month of March activity again begins in the megaspore mother cell and the nucleus enters synapsis. In the early stages the nucleolus is quite conspicuous but it later disappears. The mother cell is now quite large and its vacuolate, granular protoplasm stains more deeply than the surrounding tissue (Fig. 18). Occasionally an ovule is found which contains more than one megaspore mother cell. One from a collection of March 10th shows three such cells with their nuclei in synapsis (Fig. 19). No further stages in the heterotypic division were observed. Growth is resumed in the integument at the same time that the megaspore mother cell begins to grow as is indicated by its advance upon the nucellus, and the presence of spindles in its cells (Fig. 18). By the time that the two cells produced by the heterotypic division are organized the integument has enclosed the nucellus completely and elongated so much beyond it that these cells now appear toward the base of the ovule. These two cells now divide to form four megaspores and the upper three gradually disintegrate (Figs. 22, 55). Remnants of these are frequently visible as darkly stained masses (Fig. 23).

The development of the embryo sac conforms to the normal type. The nucleus of the functional megaspore divides and the resulting nuclei move one to each end of the sac. The sac is considerably elongated by this time and the protoplasm much vacuolated (Fig. 23). It is usual for the chalazal nucleus to divide a little before the upper so that for a short time the sac is 3-nucleate.

The embryo sac in the 4-nucleate stage is still more elongated, one-half being swollen and flared gradually toward the micropylar end (Fig. 24). The sac at this stage rather closely resembles that of *Digitalis purpurea* (2), and it is not so much unlike that of *Pentstemon secundiflorus* except for the greater elongation of the chalazal end in that species (10). Evans considered this elongation the most striking in the entire family of the Scrophulariaceae. The change from a 1- to a 4-nucleate sac takes place during the time that the corolla is expanding out of the calyx, and the sac apparently remains in this condition for several days, at least until the corolla has fallen off. The flowers begin to open in this locality about the first of April and continue to bloom for about one month.

Almost simultaneously with the appearance of the 8-nucleate stage the polar nuclei, one at each end of the sac, become recognizable by their larger size (Figs. 25, 26). These soon move toward each other until they meet near the middle of the sac. The polar nuclei may fuse

at other places, but they were found so repeatedly just at the entrance to the narrow part of the sac that one is led to conclude that this is the usual place of fusion.

Figure 27 shows an 8-nucleate sac. The polar nuclei are just in position for fusion. The three small antipodals are clear and distinct, and one lies somewhat in advance of the others. This is the usual position of the antipodals, though they are occasionally in a row one above the other (Fig. 28). The egg apparatus consists as usual of two pear-shaped synergids and an egg which is slightly larger than the synergids. The egg has its nucleus in the lower end and a large vacuole in the micropylar end. Its protoplasm seems slightly more dense and granular than that of the synergids, and stains somewhat darker. The vacuoles and nuclei are arranged in just the reverse order in the synergids.

The antipodals usually disappear soon after the complete fusion of the polar nuclei. Often they show signs of disintegration before the polar fusion is completed. This seems to be true in general for the family, though in a few species that have been studied no antipodals were observed. Schmid did not find any in *Melampyrum*, *Antirrhinum majus*, or in *Linaria vulgaris* and *Linaria alpina* (20). Balicka-Iwanowski states that the antipodals are perfectly distinct and persistent in *Linaria Cymbalaria* until the time of the complete formation of the chalazal haustorium (2). Either the behavior of the antipodals varies in the different species of *Linaria* or else Schmid did not have material showing this particular stage. Balicka-Iwanowski further states that none of the Rhinanthae present any very distinct antipodals except *Pedicularis sylvatica*.

The protoplasm of the embryo sac is exceedingly vacuolated, so much so that often only web-like strands which suspend the nuclei in place seem to be left after fixation and staining. There are certainly no starch grains stored here as in the case of *Pentstemon secundiflorus* which Evans reports as having a strikingly large amount, particularly before the time of fertilization (10).

Nucellus

A nucellus consisting of one layer of cells surrounds the megaspore mother cell. Later when growth is resumed in the spring the single massive integument grows up around and far beyond the nucellus, which, with its included megaspore, now lies in the lower part of the ovule (Fig. 55). The cells of the nucellus are long and narrow, par-

ticularly after the cell enclosed by them increases in size, and their transverse walls are usually oblique (Figs. 21, 22). The developing embryo sac breaks through the nucellus at the micropylar end and grows on beyond leaving the nucellus to surround only the narrow chalazal end of the 8-nucleate sac (Fig. 27). The nucellar cells soon collapse, the nuclei disintegrate, and by the time that two to four endosperm nuclei have been formed the nucellus has completely disappeared.

A single-layered nucellus of transitory nature has been reported for *Pentstemon secundiflorus* (10), *Striga lutea* (16), *Scrophularia marylandica* (19), and a persistent one for *Linaria vulgaris* (7).

Tapetal Layer

The tapetal layer appears very early as a band of cells surrounding the nucellus. They arise from the first layer of cells of the integument and begin to be differentiated by their slightly increased size and deeper staining properties as early as the 4-megaspore stage of the embryo sac (Fig. 55). These cells lie with their longitudinal axes perpendicular to the sac. The tapetum, or "nutritive jacket" as it has been termed by Coulter and Chamberlain (8), surrounds the chalazal, or narrowed portion of the sac, almost the same region as that surrounded by the nucellus, and never extends around the expanded portion of the 8-nucleate embryo sac. This layer is more persistent than the nucellus although its content later diminishes and its identity is lost by the time that the embryo sac is well filled out with endosperm cells and the embryo is well advanced. The tapetal cells have large nuclei and contain an abundance of rich protoplasm which stains darker than the surrounding tissue. These facts indicate a nutritive relation to the embryo sac. All of the species of the Scrophulariaceae thus far studied except *striga lutea* (16) show a tapetal layer present though variable in extent in the different kinds. Such a layer perhaps more completely surrounds the embryo sac in *Scrophularia marylandica* than in any other species previously reported (19).

Nutritive Tissue

During the early development of the embryo sac a mass of nutritive tissue develops in the chalazal region of the ovule. The cells of the tissue are small, have small nuclei, and stain conspicuously, indicating that they are different from the surrounding cells (Fig. 55). As the ovule matures its chalazal end pushes out somewhat laterally and the center of this projection is filled with nutritive tissue (Fig. 44). In

older ovules the middle portion of the nutritive tissue stains less than the outer region showing that food has been withdrawn by means of the chalazal haustorium which penetrates it.

In the micropylar region also, at a later period soon after the endosperm has begun to form, a similar mass of nutritive cells, two to three layers thick, develops around the lower part of the micropyle just above the tip of the embryo sac (Figs. 47, 57).

There is no micropylar nutritive tissue in *Digitalis pyrpurea*, *Linaria Cymbalaria*, and *Torenia Deli*, the last mentioned being almost completely lacking in chalazal nutritive tissue also (2).

FERTILIZATION

Numerous pollen tubes were seen in micropyles and often their swollen tips protruded within the embryo sac cavity (Fig. 33). Tangled masses of them spread out over the surface of the placenta were frequently recognizable. Since the contents of the pollen tube stain rather deeply and uniformly, no nuclei were identified within them. The pollen tube enters the embryo sac somewhat to one side and in so doing injures one of the synergids. The other synergid usually persists until after a few endosperm nuclei are formed (Fig. 33).

Two small and slightly oval sperm nuclei were seen in a number of instances. Many cases were observed where one sperm was in or near the egg. The most difficult stage to find was that of two sperms, a fused polar, and an egg in the same section, but at least four such sections were seen.

Figure 30 shows a pollen tube at the entrance of an embryo sac containing an egg, one synergid partially intact, and a fused polar nucleus. Two small sperm nuclei are visible over the egg. One of them is evidently on its way to the fusion nucleus and the other to the egg nucleus.

Figure 31 also shows two sperm nuclei. The form of the sperms was particularly distinct in this section and showed conclusively that they are somewhat elongate and slightly curved in shape. In this case the fused polar nucleus was cut off in the adjoining section.

Figure 32 illustrates the stage just following fertilization. The nucleus of the egg is large and deeply stained. The big definitive nucleus is still lying close to the egg and contains two prominent nucleoli.

It is evident that there is some variation in the rate of fusion of the egg and the sperm nucleus. In Figure 33 they have not yet fused although division has already taken place in the triple fusion nucleus

and two endosperm nuclei have been formed. The size of the egg nucleus in Figure 32 indicates that fertilization has taken place even though division has not yet occurred in the triple fusion nucleus.

It is certain, therefore, that double fertilization does occur in *Paulownia tomentosa*. In the family of the Scrophulariaceae double fertilization has previously been announced for *Digitalis purpurea*, *Linaria vulgaris*, *Melampyrum sylvaticum*, *Lathraea squamaria*, *Pedicularis foliosa*, *Striga lutea* (15), and *Pentstemon secundiflorus* (10).

The exact length of time between pollination and fertilization was not ascertained, but it is approximately a week to ten days. As has already been noted, sections from marked flowers show that the embryo sac is in the 4-nucleate stage at time of blooming and remains in this stage until the corolla falls off, a period of usually three or four days. The ovary increases rapidly in size during the next few days, the greenish style, which is about three centimeters in length, stands out conspicuously for a time then gradually begins dying from the tip downward so that by the end of a week or more the style has completely withered. Sections of ovules cut at this stage show an abundance of pollen tubes and organized egg apparatuses, large fusion nuclei about the center of the sacs, and numerous cases of sperm nuclei within egg cells. Collections of material were made at all times of the day, killed both at the tree and almost immediately in the laboratory, but no material, was collected during the night. It is evident, judging by the large number of slides observed, that actual fertilization must usually take place at night, that the fusion of the sperm nucleus with the fused polar nucleus occurs rapidly, and that the secondary endosperm nucleus travels quickly away after fusion toward the center of the sac.

FORMATION OF ENDOSPERM

Endosperm formation begins soon after fertilization. The endosperm nucleus divides and between the two nuclei which push down into the chalazal region a wall immediately forms (Figs. 33, 39). The nucleus in the lower cell divides once without any wall forming between. Division of the upper nucleus continues, followed by the formation of cell walls, but after four to six cells have formed throughout the length of the sac their nuclei divide at right angles to the length of the sac thus forming two rows of cells (Figs. 40, 41, 46). This division proceeds from the chalazal region upward. Walls appear in various planes after this time so that the original walls are soon obscured.

In the meantime the sac elongates with the growth of the ovule,

the chalazal region increases in width and the whole region of the sac extending from the egg to the chalazal end fills up with endosperm cells. Endosperm nuclei are occasionally seen in the extreme micropylar end of the sac, but no cell walls appear (Fig. 41).

During endosperm formation the tapetum stains heavily and appears to be very active during the early development of the embryo.

This method of endosperm formation conforms to that of Schmid's second group in which he placed *Linaria* and *Antirrhinum* (20). *Striga lutea* also follows this method of endosperm formation (16).

Haustoria

A haustorium shaped like a bicuspid tooth is formed at the chalazal end of the embryo sac by the bifurcation of the lower endosperm cell which has at this stage become binucleate. One of the two nuclei moves down in each fork (Figs. 42, 43, 44). The prongs of the haustorium bending 35 degrees or more from the longitudinal direction of the sac penetrate the bed of nutritive tissue in the outermost tip of the ovule (Figs. 43, 44). These are in close touch with the food brought in through the chalazal region. By the time the embryo is well advanced the haustorial tissue breaks down (Fig. 48). Two endosperm nuclei at the upper end of the sac push up into the neck of the micropyle to form a two-legged micropylar haustorium (Fig. 35). These nuclei later become very large and stain conspicuously. Cross sections of this haustorium in its lower part show the two distinct parts of the basal prongs and frequently the two nuclei appear in this region (Fig. 37). The upper part of the haustorium forms a large bulbous structure which contains one large, or several smaller vacuoles and the two big nuclei (Fig. 36). The nuclei vary in position as they are found frequently either in the basal prongs or in the enlarged upper region. The haustorium consumes a considerable portion of the integumentary cells lying around the micropyle for the benefit of the developing embryo. Later when its work is completed, its structure collapses and only a porous mass remains (Fig. 47).

There is no tapetal layer in the upper region of the sac. However, at the time when the micropylar haustorium first develops, the cells of the first integumentary layer in the uppermost region of the sac and extending into the neck of the micropyle seem quite well defined and distended (Fig. 45). These probably function as tapetal cells for a short time. Such a condition is reported to be the case in *Scoparia dulcis* (2).

EMBRYO

The fertilized egg rests until the embryo sac is well filled with endosperm (Figs. 41, 42, 45). The first division of the egg is transverse, the lower cell giving rise to the embryo and the upper to a long suspensor (Fig. 50) consisting of about six cells (Fig. 51). It pushes the embryo about one-fourth of the way down into the endosperm. The first two divisions of the embryo proper are longitudinal and at right angles to each other (Figs. 51, 52). Further division proceeds rapidly and a many-celled globular embryo is soon formed (Fig. 53). The suspensor cells break down early and soon disappear.

The first indication of the cotyledons is seen as slight projections on the outer corners of the embryo which is by this time a little longer than broad (Fig. 47). The mature embryo has two cotyledons of approximately equal length which constitute slightly less than half the total length of the embryo (Fig. 54). It fills almost the entire endosperm region, being surrounded by only two or three layers of endosperm cells in the mature ovule (Figs. 61, 62).

The embryo may not develop even though the endosperm develops in the usual manner. A great many of the ovules do not have embryos. Slide after slide, each of which contained many sections through ovules whose sacs were filled with endosperm, was examined which showed only one or two embryos or quite frequently none in the whole number of ovules on a slide. Cook reports a similar observation for *Linaria vulgaris*, which also has many small seeds in a single ovary (7). He says that the majority of ovules in this species do not have embryos and that in some cases perhaps whole ovaries may be without them. Many mature seed of *Paulownia* appearing normal externally show upon examination with the low power of the microscope a mass of almost translucent endosperm tissue uniform in density throughout whereas those containing embryos show a dense, dark mass filling most of the embryo sac region.

CHANGES IN THE ENDOSPERM AND DEVELOPMENT OF THE SEED COAT

Soon after the haustoria begin to function the first two or three layers of endosperm cells in the haustorial regions begin to show by their denser protoplasm and greater capacity for stain that they are filling up with nutritive material. This storage of food material begins first in the chalazal region and is soon followed by the same behavior in the micropylar region (Figs. 47, 48). As growth continues, the accumulation of

food material extends to all the endosperm cells throughout the entire length of the ovule so that the growing embryo is surrounded by cells well supplied with food. The mature embryo is surrounded by a few collapsed endosperm cells which have been exhausted of food and crowded together, and by two or three layers of endosperm cells around the outside that remain gorged with food material to be used later for nourishing the seedling (Figs. 61, 62).

The seed coat consists of two layers which become differentiated from the cells of the integument (Figs. 61, 62). The layer of cells lying next to the embryo sac become lignified and are more or less quadrangular in cross section. This layer corresponds to what Bachmann has termed the quadratic, or inner layer (1). The walls of these cells become considerably thickened, and in fact, in the mature seed, seem to make up the greater part of the cell (Fig. 60). Despite the thickening of the walls this layer often appears somewhat sinuous due to slight infoldings into the endosperm. These slight curves do not noticeably affect the outer surface of the seed. The walls of the inner layer become slightly brownish upon ripening.

The outer layer of the seed coat consists of almost transparent cells. The outer cells covering the two longitudinal surfaces of the ovule follow the general shape of the inner cells, the tangential diameter being the greater. The end walls are slightly thickened so that the ends of the cells where they meet are fairly well supported. The ends of adjoining cells are similarly thickened throughout the length of the ovule, but the outer surface walls of the cells being unsupported in any way tend to sag and this accentuates the elevations at the ends of the cells so that there appear to be a few faint longitudinal striations on the outer surface. Along the sides of the ovule a few cells expand outward to varying lengths so that the outermost margin is not more than two cells in thickness thus forming light delicate appendages resembling somewhat the wings of a small insect. All the walls of the cells of the outer layer except the outer surface are strengthened by net thickenings. Viewed from the outer surface these thickenings in the cell walls appear as in Figure 58, or when looked at in cross section as in Figures 59 and 62.

THE SEEDLING

Paulownia seeds planted in soil germinate within a few days. The tiny seedling pushes through the soil with its two cotyledons often still enclosed in the old seed coat, but by the time that it is a centimeter or

so tall the cotyledons expand enough to push off the seed coat entirely. The seedling sends down one little root which has a scanty supply of root hairs just below the surface of the soil. It is exceptionally small and delicate, appearing much less sturdy than a radish seedling, and grows slowly. Some seedlings grown in soil in the laboratory were barely 1.5 cm. tall when three weeks old and the cotyledons, or first leaves, were not much larger than they were at the time when the seed coat was shed. This delicate seedling is in odd contrast to the superlatively vigorous tree which grows like Jack's bean-stalk. Stump shoots have grown 21 feet in one season.

SUMMARY

1. *Paulownia tomentosa* Steud. is an introduced plant belonging to the sub-family Antirrhinoideae of the Scrophulariaceae. It grows to tree size.

2. The microsporangia develop as usual. The wall of the sporangium has an epidermal layer, three to four wall layers, and a tapetal layer.

3. The microspore tetrad is developed in the usual way.

4. The microspores are formed in September.

5. The 2-nucleate male gametophytes were observed in October. These spend the winter in this stage.

6. The generative nucleus does not divide before the shedding of the pollen.

7. Artificially germinated pollen grains showed only the tube nucleus and the generative nucleus in the pollen tubes.

8. The pollen grain has three pores in the exine for the exit of the pollen tube.

9. The ovary is bilocular and the ovules are anatropous with one thick integument.

10. The megaspore mother cell is formed directly from a subepidermal cell in August. As usual it produces four megaspores, the lower one forming the embryo sac.

11. The 8-nucleate embryo sac develops as usual. It contains one large egg, two synergids, two polar nuclei, and three small antipodals which degenerate early.

12. The micropylar end of the sac becomes bulbous while the chalazal end becomes long and narrow. The polar nuclei fuse in the mid-region of the sac just within the bulbous region.

13. Pollen tubes enter the embryo sac, but do not penetrate the egg cell.

14. Double fertilization occurs.

15. The nucellus consists of a single layer of cells which surround the megaspore, and break down early.

16. A single layer of tapetal cells develops around the chalazal portion of the sac. It begins to be differentiated at the time the functional megaspore divides.

17. The first layer of cells of the integument in the micropylar region functions as a nutritive layer during the formation of the micropylar haustorium.

18. Endosperm is formed by cell division and begins before the fertilized egg divides.

19. There is a large mass of nutritive tissue in the chalazal region of the ovule and a small one around the base of the micropyle. A long, curved, two-pronged, binucleate haustorium forms at the chalazal end and penetrates the nutritive tissue there, while a large bulbous haustorium protrudes into the micropyle and is surrounded in its lower region by a small mass of nutritive tissue.

20. The proembryo has a suspensor of about six cells.

21. The mature embryo has two cotyledons and is surrounded by two to three layers of endosperm cells gorged with food materials.

22. A large percentage of ovules do not develop embryos, but the endosperm develops normally even in the absence of an embryo.

23. The seed coat consists of two layers of cells, an inner layer of thick-walled lignified cells, and an outer almost transparent layer which is expanded on each side to form wing-like outgrowths.

24. The seedling is exceptionally small and delicate.

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EXPLANATION OF PLATES

All drawings were made at table level with the aid of a Spencer camera lucida and reduced. The figures are so placed that the micropylar end of the embryo sac is turned toward the bottom of the page.

Abbreviations: *ant.*, antipodals; *c.h.*, chalazal haustorium; *cot.*, cotyledon; *e.*, egg; *emb.*, embryo; *emb. s.*, embryo sac; *emb. c.*, embryo cells; *end. c.*, endosperm cells; *ep.*, epidermis; *f. n.*, fusion nucleus; *fun.*, funiculus; *g. c.*, gelatinized cells; *l. c.*, lignified cells; *mic.*, micropyle; *m. h.*, micropylar haustorium; *n. t.*, net thickenings; *nuc.*, nucellus; *nut.t.*, nutritive tissue; *o.l.*, outer layer; *p.s.op.*, pollen sac opening; *p.t.*, pollen tube; *s.*, sperm; *sp.t.*, sporogenous tissue; *sp.m.c.*, spore mother cell; *sus. c.*, suspensor cell; *s.w.*, seed wing; *syn.*, synergid; *t.*, tapetum; *t.f.n.*, triple fusion nucleus; *t.n.*, tube nucleus.

PLATE 4

Paulownia tomentosa Steud.

1. Section of anther showing differentiation of sporogenous tissue; ×266.
2. Sporogenous tissue of four layers surrounded by tapetal cells; ×585.
3. Spore mother cells surrounded by tapetal cells some of which are binucleate; ×266.
4. Diad stage of spore mother cells which are enclosed by large, binucleate tapetal cells, four parietal layers, and epidermis; ×266.
5. Tetrad stage of spore mother cells; ×266.
6. Segment of anther wall of March 10th showing tapetal cells still present and binucleate spores; ×266.
7. Segment of anther wall of April 11th showing complete disappearance of tapetum; ×60.
8. Spore mother cell with spindle in late metaphase stage in preparation for the diad stage; ×585.
9. Diad stage of spore mother cell; × 585.
10. Spindles preceding the formation of a tetrad; ×585.
11. Tetrad of spores within old mother cell wall; ×585.
12. Mononucleate spore of September 4th; ×585.
13. Binucleate spore of October 17th; ×585.
14. External view of mature spore; ×585.
15. Pollen tube sprouted in 5% sugar solution showing tube nucleus and generative nucleus (fixed by Carnoy's fluid and stained by Feulgen's method); ×585.
16. Half of cross section of anther showing location of two of the four pollen sacs and point of dehiscence; ×30.

17. Archesporial mother cell in young ovule. Origin of integument becoming visible; ×585.
18. Archesporial mother cell in synapsis. Indications of nuclear activity in cells of integument of March 10th; ×585.
19. Unusual case of three archesporial cells in one ovule in synapsis on March 10th; ×585.
20. Two cells formed by first division of megaspore mother cell enclosed by a 1-layered nucellus; ×266.
21. Four megaspores surrounded by nucellus; ×266.
22. Lower functional megaspore with three upper megaspores in stage of degeneration; ×585.
23. Two-nucleate embryo sac. Remnants of three upper megaspores present; ×585.
24. Four-nucleate embryo sac; ×585.
25. Chalazal end of embryo sac showing three antipodal cells, and lower polar nucleus. The degenerating nucellus and a well developed tapetum adjoin this region; ×585.
26. Four nuclei in micropylar end of sac. Polar nucleus distinctly larger than others. ×573.

PLATE 5

Paulownia tomentosa Steud.

27. Eight-nucleate embryo sac. Egg apparatus organized. ×285.
28. Seven-nucleate sac showing fusion nucleus and degenerating antipodals; ×285.
29. Fusion nucleus in region of the egg apparatus; ×585.
30. Double fertilization. One sperm nucleus is just above the fusion nucleus and the other is near the egg nucleus; ×573.
31. Two sperms lying over the egg and in the region of the egg nucleus. One synergid still intact. ×573.
32. Triple fusion nucleus in position for movement away from the fertilized egg and remaining synergid; ×573.
33. Pollen tube in neck of micropyle and sperm nucleus within the egg. Two endosperm nuclei in lower part of sac with indication of wall formation between them. ×285.
34. Cross section of ovule showing epidermis, integument, tapetum, nucellus and embryo sac; ×266.
35. Binucleate micropylar haustorium. Group of nutritive cells at base of micropyle. ×285.
36. Cross section through bulbous portion of micropylar haustorium containing two nuclei and surrounded by nutritive cells; ×285.
37. Cross section through lower part of micropylar haustorium showing two distinct parts, each containing a nucleus; ×285.
38. Micropylar haustorium with very large vacuole and two big nuclei. Endosperm cells adjoining the haustorium. ×285.
39. Two endosperm nuclei in chalazal region of sac. Remnants of antipodals and nucellus still present, but their nuclei almost degenerated; ×285.
40. Four endosperm nuclei. One cross wall has formed and the lower cell gives evidence of bifurcation. ×285.

41. Embryo sac containing four endosperm cells, a fertilized egg, and two free endosperm nuclei in micropylar end of sac; ×285.
42. Similar to Fig. 40 except that the lower chalazal cell is partly bifurcated. The fertilized egg and one endosperm nucleus in the micropylar region. ×285.
43. Two-pronged chalazal haustorium. Endosperm nuclei dividing at right angles to the length of the sac and walls forming between; ×285.
44. Chalazal haustorium surrounded by mass of small nutritive cells in tip of ovule; ×285.
45. Embryo sac containing two rows of endosperm cells and a fertilized egg. Section of micropylar haustorium in micropyle. First layer of integumentary cells conspicuous around upper portion of sac. ×160.
46. Stage similar to Fig. 45. Fertilized egg conspicuous. ×285.

PLATE 6

Paulownia tomentosa Steud.

47. Micropylar end of older ovule showing collapsed micropylar haustorium, mass of nutritive cells around neck of micropyle, gelatinized cells at entrance to micropyle, outer rows of endosperm cells containing surplus food material, layer of lignified cells indicated by dark line, and embryo with beginning cotyledons. ×30.
48. Chalazal end of older ovule showing complete disappearance of haustorium, mass of nutritive cells in tip of ovule, and endosperm cells in chalazal part of sac containing surplus food material; ×266.
49. Fertilized egg beginning to enlarge; ×573.
50. First division of fertilized egg forming first cell of embryo and suspensor cell; ×573.
51. Young embryo with 6-celled suspensor; ×585.
52. Cross section of 4-celled embryo; ×585.
53. Advanced embryo now globular in shape. Nuclei of suspensor cells disintegrating. ×585.
54. Outline of older embryo showing cotyledons; ×60.
55. Section through young ovule showing its shape at the time when the megaspores are present; ×585.
56. Shape of ovule at time of endosperm and haustoria formation; ×69.
57. Longitudinal section through young seed; ×30.
58. Appearance of net thickening of wing of seed from surface view of portion of two cells; ×285.
59. Cross section of outer margin of wing showing net thickening of cell walls; ×285.
60. Inner surface view of group of cells from lignified layer of seed coat; ×160.
61. Section from a mature seed showing an outer layer, an inner layer of lignified cells, several layers of endosperm cells, and a section of the embryo; ×285.
62. Cross section of mature seed showing cells of wings with net thickenings, layer of lignified cells, endosperm cells, and cotyledons; ×41.

PLATE 4

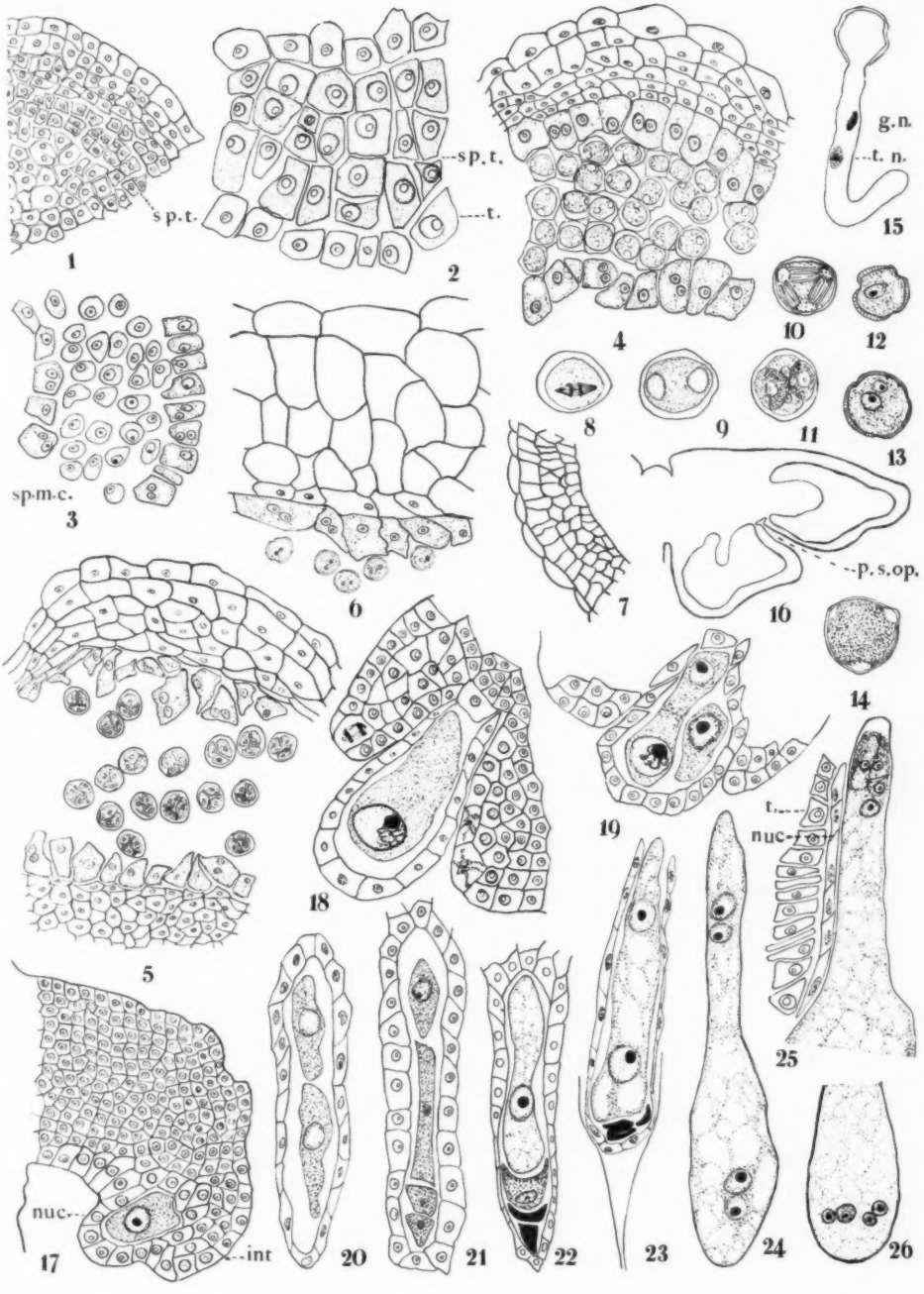
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PLATE 5

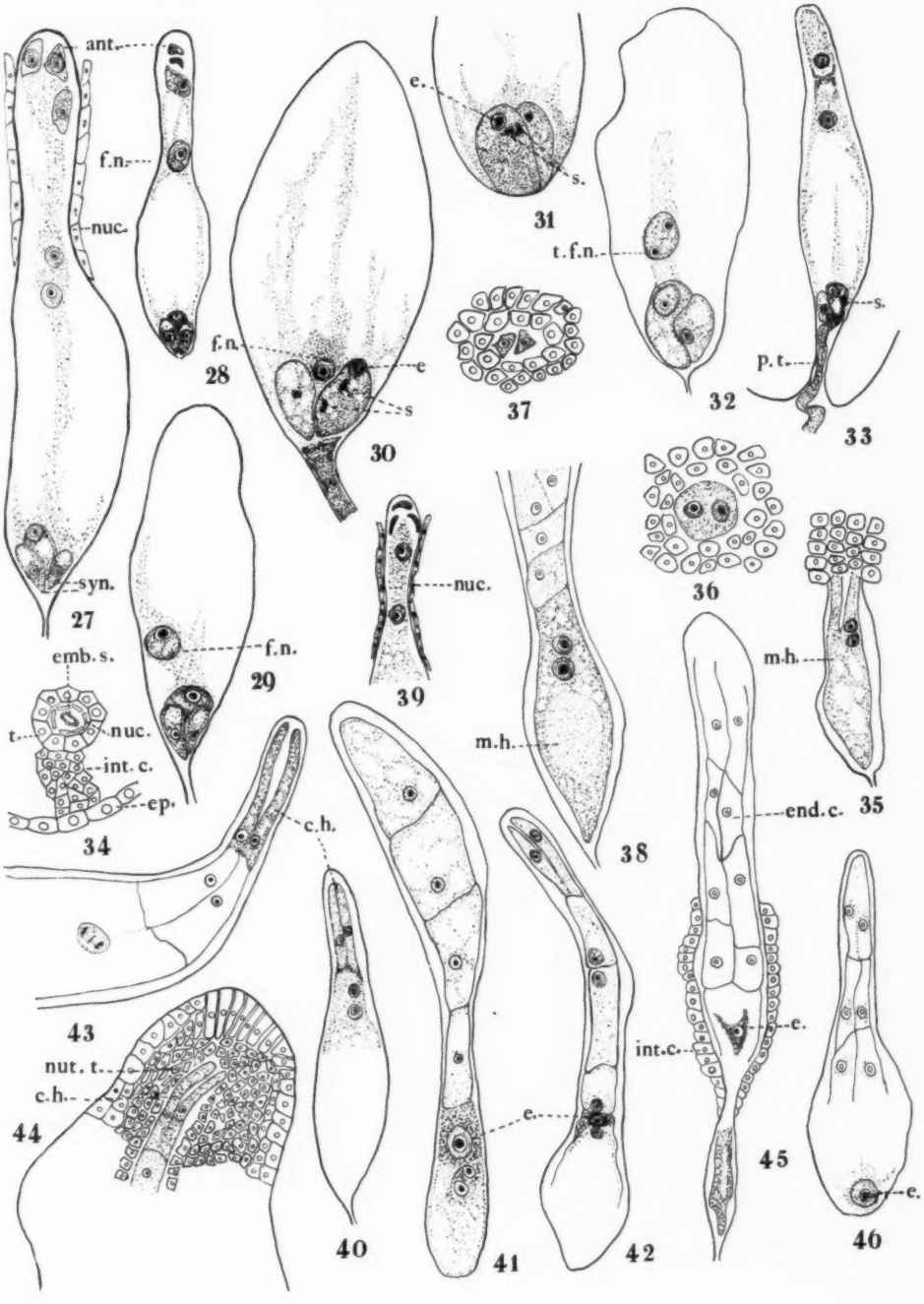
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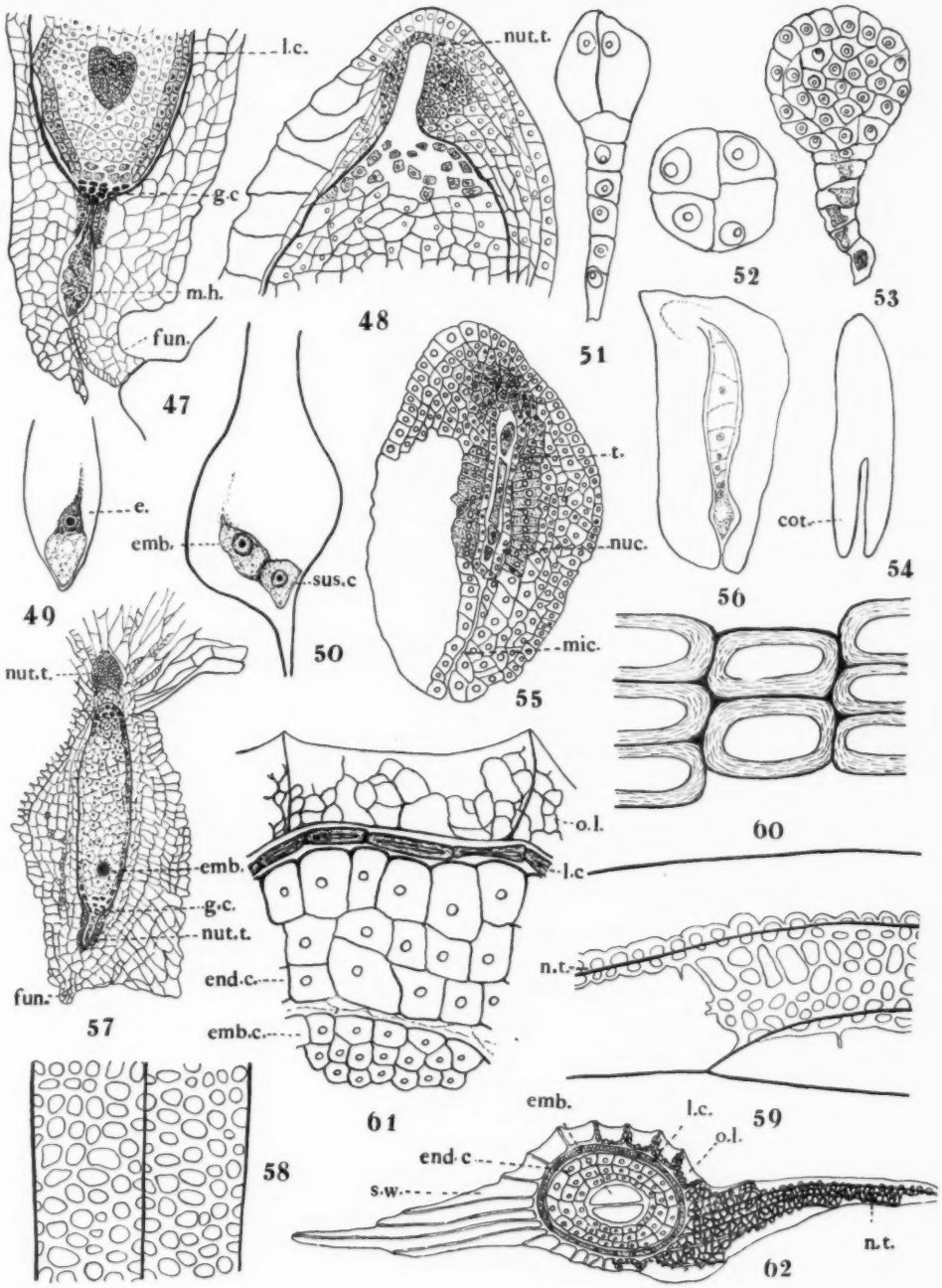
PLATE 6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A FIELD TRIP TO THE DEVIL'S MILLHOPPER[1]

By Lillian E. Arnold

Plates 7–10 and 1 Text Fig

An interesting locality for a botanical study is found at the Devil's Millhopper,[2] a large, deep limestone sink located six miles northwest of Gainesville, Florida. Its fascination is such that it has become a mecca for visiting botanists at all times of the year. The sink can be detected from a distance by the dense growth of woody plants which attracts the eye amidst an area of broad, flat, cut-over and burnt-over pineland on which *Quercus Catesbaei*[3] has become established. Closer inspection reveals that the vegetation here differs very greatly from that of the surrounding territory. Its interest lies in this thick growth of an extensive mesophytic and semi-hydrophytic flora at a station situated in an area of more or less semi-xerophytic type. Although sinks are not uncommon in this region of the state, it seldom happens that their vegetation differs so strikingly from that of the surrounding territory, as it usually takes its type from the area in which the sink occurs. Sinks occurring in hammocks are usually occupied by hammock vegetation, while those in scrubby regions maintain a scrubby type of vegetation.

PHYSIOGRAPHY

The age of a sink hole can be judged by its shape, as new ones have almost perpendicular sides. Gradually plants move into the sides, but until the woody plants become established, the sides will continue to

[1] During the period extending from the fall of 1929 through the spring of 1933, a floristic study was made of the ferns and higher plants which occur conspicuously at this station and the complete study, entitled "A Study of the More Conspicuous Flora of the Devil's Millhopper," was presented in partial fulfillment of the requirements for the degree of Master of Science at the University of Florida in January, 1934.

[2] In June 1935, forty acres of land including the Millhopper were purchased by the Junior Chamber of Commerce of Gainesville with a view of making it into a public park.

[3] Nomenclature of Spermatophyta follows: Small, John K. Manual of the Southeastern Flora. 1554 pp. Illus. Author, 1933.

shelve, because the early plant associations do not bind the soil sufficiently to check further talusing. However, over the course of many years erosion is bound partly to fill the cavity, so that very old sinks can be recognized by their gently sloping sides and shallowness, as well as by the fact that the outlets for drainage have become clogged.

A survey of the Devil's Millhopper has shown that it is approximately 114 feet deep, 500 feet in diameter at the top and 60 feet at the bottom. Its banks incline at angles between 30° and 35° with the horizontal. About half way down the incline, there is a ledge 25 to 30 feet wide, which extends practically all the way around the sink and forms a good point of vantage from which to view the base. On the basis of these facts, the Devil's Millhopper is an old sink; probably as much as one thousand years.

The very prominent ledge which encircles the sink at about half its depth indicates that there probably have been two distinct cave-ins. This theory seems to be substantiated by the presence of several specimens of very large trees that stand in the area between the ledge and the perimeter of the sink, for these trees, which will be discussed later, have proved by measurement to be the largest of their species growing anywhere in this sink. The first cave-in may have occurred to this depth, and the action of the water continued to deepen it to its present level. Even now the cavity does not extend as deep as the surface of the water-table, because the water does not stand in it. An interesting subject for conjecture is whether further erosion will cause another cave-in to the depth of the water-table, or whether debris will accumulate and fill it. This will depend upon the composition of the soil underlying its present bottom.

A geological study was made of this station by Cooke and Mossom[4] and their data are as follows: "The Devil's Millhopper, a sink 6 miles northwest of Gainesville, cuts through at least 115 feet of Hawthorn beds to the Ocala limestone, which doubtless lies not far below water level. The following section at the Devil's Millhopper was measured by Cooke in 1913:

Hawthorn formation:

	Feet
10—Covered; debris of calcareous sandstone	25
9—Gray or cream-colored calcareous sandstone or sandy limestone containing round phosphatic grains, poorly preserved mollusks, and echinoids; lower part more sandy and paler than upper; this bed has slumped several feet	15

[4] Cooke, C. Wythe, and Stuart Mossom. Geology of Florida. 20th Ann. Rept. Fla. State Geol. Survey, 129. 1929.

	Feet
8—Concealed; partly encrusted with travertine	27
7—Green sandy clay, upper part encrusted with travertine 1 inch to more than 4 inches thick and enclosing land shells	9
6—Hard silicified green clay or fuller's earth	5
5—Greenish-gray sand and fuller's earth	15
4—Covered	
3—Hard cream-colored or yellow phosphatic fossiliferous limestone at base passing upward into sandy phosphatic limestone; probably a fallen block of bed 9	11
2—Soft calcareous sand with brown phosphatic pebbles and moulds of fossils; seen below waterfall on west side	2
1—White calcareous sandstone with phosphatic nodules; to water level	5''

From this study it is noticeable that most of the soil in this station is of calcareous origin.

METEOROLOGICAL CONDITIONS

The banks of this sink from the outer rim to the ledge are so heavily wooded for the entire circumference, that only a filtered light reaches the forest floor of this area. From the ledge to the bottom of the incline, the stand of trees is thinner, which permits direct sunlight to penetrate more readily, except on the south side with the northern exposure. The east, north, and west sides receive a little direct sunlight at some time of the day, while the mud bottom revels in sunlight from the time the sun shines over the tree tops on the east until it sets behind the tree tops.

The largest waterfall is located on the west side, where a surface drainage stream has worn a small ravine down to the ledge, from whence it splashes over the rocks in a succession of falls to the bottom. Here it wanders in a northerly direction until the water disappears under a large rock on the north side of the bottom. Two seepage streams appear as springs at or near the ledge on the south and southwest sides, from whence the waters fall to the bottom in two series. During the four-year period of study, these three streams were never observed to have dried up entirely. During very rainy periods seepage water oozes into the sink on all sides, but does not accumulate into well-defined streams.

During the years 1931–32 and 1932–33, there was an intermittent drought on the eastern seaboard and particularly in Florida. In these two particularly dry years the water of the spring freshets soon vanished from sight through the underground outlet indicating that the

water-table had fallen. During this period of extreme drought the principal points of drainage into the underground stream were apparent. While there seems to be a certain amount of seepage draining into the cavity from half a dozen sources, still the water from these sources is never sufficient to cause more than a small stream at the bottom. In times of abnormal rainfall the water in the sink may reach a depth of approximately 15 feet, as indicated by the growth of perennial plants on higher levels.

When the bottom is completely or partly filled with water, there are no plants on the floor, yet it is exceedingly interesting to note the number and variety of annuals and the few perennials that spring up as soon as this pool is reduced to the small drainage stream. During the years, 1931–32, 1932–33, it was so dry that the bottom of this sink became solid enough to walk upon and the invasion of the pioneer flora, which is fully waist high in some places, has bound the soil even more firmly. Thus, this bottom growth here forms a distinct contrast to the plant associations occurring on the banks at higher levels. These banks are thickly wooded with a variety of very fine specimens of trees, while the floor of this forest is heavily covered with ferns, especially on the south side which lacks direct sunlight.

In February 1933 a fire in the pine flats at the north of this sink crept into it as far as the ledge on the north side. *Dryopteris* and *Rhapidophyllum* specimens were badly injured, but were not killed. Several oaks were scarred so badly that they show signs of dying. However, taken as a whole, the damage was slight.

FLORISTICS

Floristic studies naturally resolve themselves into investigation of the four regions or zones delimited by the topography of the station. These zones (Fig. 1) are based solely on the topography and do not seem to bear any relation to the geological strata. Although there are no clear-cut marks of definition between these zones, still certain species occur in one zone that do not occur in others, as shown in Table 1. However, only the most conspicuous species are pointed out in the following discussion.

In order to secure an idea of the relationship of the flora of this station to that of the territory immediately surrounding it, the outer zone was arbitrarily defined to extend to a distance of 20 to 25 feet from the perimeter of the sink and has been designated as Zone 1. The area from the abrupt rim of the sink to the ledge has been designated as

Zone 2. The banks extending from the ledge to the bottom of the incline have been designated as Zone 3, while the area of the recently exposed mud bottom, which has furnished a study of pioneer associations, has been designated as Zone 4. These four zones, based solely on greatly contrasting topographical conditions occurring in a distinctly limited area, afford the best means of making the ecological study of the flora within this station, as well as with that of the surrounding terrain.

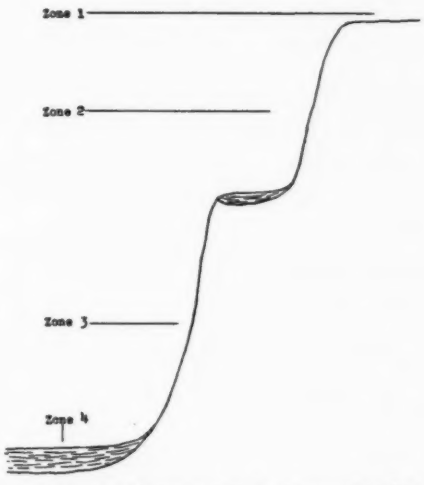

FIG. 1. DIAGRAMMATIC SKETCH SHOWING THE CONTOURS OF A SIDE OF THE DEVIL'S MILLHOPPER AND THE LOCATION OF ZONES

Zone 1

The car trail leading from the paved highway ends suddenly on the southern brink of the sinkhole under some large specimens of *Hicoria glabra* and a damaged individual of *Padus virginiana*, the only one at this station, that still stands toweringly with a few branches at the top. Measurements show that it has a girth of 6 feet 9 inches at a point 3 feet from the ground. Alighting from the car at this point, a walk around the periphery reveals much shrubby growth on the margin intermingled with many good-sized examples of *Nyssa sylvatica*, *Carpinus caroliniana*, *Quercus nigra*, and *Ostrya virginiana*, while much of the floor is carpeted with the mottled-leaved species of violet, *Viola Walteri*. The northeast and eastern sectors display interesting

TABLE 1

List of the flora of the Devil's Millhopper, showing distribution of species by zones
(S indicates sparing; M indicates moderate; A indicates abundant)

FAMILY AND PLANTS	ZONE			
	4	3	2	1
Polypodiaceae:				
Polypodium Plumula H. B. K.		S		
Polypodium polypodioides (L.) A. S. Hitch.		M		
Pycnodoria Cretica (L.) Small		A	A	
Adiantum tenerum Sw		S		
Asplenium resiliens Kunze			S	
Asplenium heterochroum Kunze			S	
Dryopteris floridana (Hook.) Kuntze		A	A	
Dryopteris normalis C. Chr.		A	A	
Pinaceae:				
Pinus taeda L.			S	S
Pinus glabra Walt.			S	S
Poaceae:				
Paspalum longepedunculatum LeC.	A			
Oplismenus setarius (Lam.) Roem. & Schult.		A	A	
Panicum Joorii Vasey		A	A	
Trisetum pennsylvanicum (L.) B. S. P.	A			
Eleusine indica (L.) Gaertn.	A			
Uniola laxa (L.) B. S. P.			S	
Cyperaceae:				
Cyperus virens Michx.	A			
Kyllinga pumila Michx.	M			
Carex stipata Muhl.	A			
Carex dasycarpa Muhl.				S
Carex lupulina Muhl.	A			
Arecaceae:				
Sabal minor (Jacq.) Pers.			S	S
Rhapidophyllum Hystrix (Fraser) H. Wendl.			S	S
Araceae:				
Arisaema acuminatum Small		A	A	
Muricauda Dracontium (L.) Small		M	M	
Commelinaceae:				
Commelina erecta L.			S	S
Commelina angustifolia Michx.				S
Bromeliaceae:				
Dendropogon usneoides (L.) Raf.				A
Tillandsia tenuifolia L.			S	

TABLE 1—*Continued*

FAMILY AND PLANTS	ZONE			
	4	3	2	1
Smilacaceae:				
Smilax glauca Walt.		M	M	M
Smilax auriculata Walt.		A	A	A
Smilax laurifolia L.		A	A	A
Smilax pumila Walt.		M	M	M
Tamaceae:				
Dioscorea floridana Bartlett			S	
Orchidaceae:				
Ponthieva racemosa (Walt.) C. Mohr.			S	
Malaxis spicata Sw.			S	
Tipularia unifolia (Muh.) B. S. P.				?
Amphiglottis conopsea (Ait.) Small.			S	
Saururaceae:				
Saururus cernuus L.	S			
Juglandaceae:				
Hicoria glabra (Mill.) Britton				A
Salicaceae:				
Salix longipes Anders	S			
Corylaceae:				
Carpinus caroliniana Walt.		A	A	A
Ostrya virginiana (Mill.) Willd.		A	A	A
Fagaceae:				
Quercus Prinus L.			S	M
Quercus virginiana Mill.			S	M
Quercus nigra L.				M
Quercus laurifolia Michx.				S
Urticaceae:				
Adicea pumila (L.) Raf.	A	M		
Boehmeria cylindrica (L.) Willd.		A		
Artocarpaceae:				
Morus rubra L.			S	
Ulmaceae:				
Ulmus alta Michx.		S		
Celtis georgiana Small			S	
Polygonaceae:				
Persicaria hydropiperoides (Michx.) Small	A			
Persicaria setacea (Baldw.) Small	A			
Amaranthaceae:				
Iresine Celosia L.	S			
Phytolaccaceae:				
Phytolacca rigida Small		S		M
Ranunculaceae:				
Viorna reticulata (Walt.) Small				S

TABLE 1—*Continued*

FAMILY AND PLANTS	ZONE			
	4	3	2	1
Annonaceae:				
Asimina parviflora (Michx.) Dunal			S	
Magnoliaceae:				
Magnolia grandiflora L.		A	A	A
Brassicaceae:				
Radicula Walteri (Ell.) Small	A			
Iteaceae:				
Itea virginica L.		M		
Altingiaceae:				
Liquidambar Styraciflua L.		A	A	A
Rosaceae:				
Rubus floridus Tratt.		A		
Rubus trivialis Michx.				A
Agrimonia microcarpa Wallr.			S	
Amygdalaceae:				
Prunus angustifolia Marsh.				M
Padus virginiana (L.) Mill.				S
Cassiaceae:				
Chamaecrista brachiata Pollard				M
Fabaceae:				
Baptisia leucantha T. & G.				S
Erythrina herbacea L.				S
Phaseolus polystachyus (L.) B. S. P.		A	A	
Meibomia grandiflora (Walt.) Kuntze.		S		
Lespedeza hirta (L.) Ell.				S
Oxalidaceae:				
Xanthoxalis stricta (L.) Small	M			
Xanthoxalis corniculata (L.) Small	M			
Rutaceae:				
Zanthoxylum Clava-Herculis L.			S	
Meliaceae:				
Melia Azedarach L.			S	
Euphorbiaceae:				
Bivonea stimulosa (Michx.) Raf.				S
Spondiaceae:				
Toxicodendron radicans (L.) Kuntze.		A	A	M
Toxicodendron Toxicodendron (L.) Britton		A	A	
Aquifoliaceae:				
Ilex ambigua (Michx.) Chapm.			S	S
Ilex opaca Ait.			M	
Celastraceae:				
Euonymus americanus L.		A	A	

TABLE 1—*Continued*

FAMILY AND PLANTS	ZONE			
	4	3	2	1
Frangulaceae:				
Ceanothus intermedius Pursh	S			
Vitaceae:				
Muscadinia rotundifolia (Michx.) Small		A	A	
Ampelopsis arborea (L.) Rusby		A	A	
Parthenocissus quinquefolia (L.) Planch.		A	A	A
Tiliaceae:				
Tilia heterophylla Vent		M	M	
Malvaceae:				
Sida rhombifolia L	M			
Sida carpinifolia L. f				M
Cistaceae:				
Crocanthemum corymbosum (Michx.) Britton	S			
Violaceae:				
Viola sororia Willd	M	A		
Viola septemloba LeConte				S
Viola Walteri House			A	A
Passifloraceae:				
Passiflora lutea L			S	
Lauraceae:				
Tamala Borbonia (L.) Raf			S	
Nyssaceae:				
Nyssa sylvatica Marsh			S	
Svida microcarpa (Nash) Small			M	
Cynoxylon floridum (L.) Raf			A	
Ammiaceae:				
Eryngium Baldwinii Spreng	S			
Sanicula Smallii Bicknell			S	
Sanicula canadensis L		S		
Sanicula floridana Bicknell			M	
Hydrocotyle umbellata L	A			
Hydrocotyle verticillata Thun		M		
Ptilimnium capillaceum (Michx.) Raf	A			
Vacciniaceae:				
Polycodium neglectum Small				S
Primulaceae:				
Samolus floribundus H. B. K	A			
Sapotaceae:				
Bumelia lanuginosa (Michx.) Pers			S	
Oleaceae:				
Fraxinus pauciflora Nutt	S			

TABLE 1—*Continued*

FAMILY AND PLANTS	ZONE			
	4	3	2	1
Oleaceae (*Continued*):				
Fraxinus americana L.		M		
Chionanthus virginica L.			S	
Amarolea floridana (Chapm.)			M	
Spigeliaceae:				
Gelsemium sempervirens (L.) Ait. f.				M
Asclepiadaceae:				
Amphistelma scoparia (Nutt.) Small		M	M	
Dichondraceae:				
Dichondra carolinensis Michx.	S			
Solanaceae:				
Physalis pubescens L.	S			
Physalis pruinosa L. (?)	S			
Physalis barbadensis Jacq.	A			
Physalis angulata L.	A			
Solanum gracile Link	S	A		
Boraginaceae:				
Lithospermum tuberosum Rugel		S		
Verbenaceae:				
Callicarpa americana L.			S	M
Lamiaceae:				
Trichostema dichotomum L.				S
Salvia lyrata L.			S	
Monarda punctata L.				S
Hyptis pectinata (L.) Poir.				S
Acanthaceae:				
Ruellia hybrida Pursh				M
Bignoniaceae:				
Anisostichus crucigera (L.) Bureau				S
Rubiaceae:				
Houstonia procumbens (Walt.) Standley				S
Cephalanthus occidentalis L.	S			
Mitchella repens L.		A	A	A
Galium pilosum Ait.	S	M	M	
Caprifoliaceae:				
Sambucus Simpsonii Rehder		M		
Viburnum rufidulum Raf.				M
Viburnum obovatum Walt.				M
Phenianthus sempervirens (L.) Raf.				S
Valerianaceae:				
Valeriana scandens L.	M	A	A	
Cucurbitaceae:				
Melothria pendula L.		M	M	
Lobeliaceae:				
Lobelia puberula Michx.				S

TABLE 1—*Concluded*

FAMILY AND PLANTS	ZONE			
	4	3	2	1
Ambrosiaceae:				
Ambrosia elatior L.				S
Carduaceae:				
Vernonia ovalifolia T. & G.				M
Elephantopus tomentosus L.				M
Eupatorium capillifolium (Lam.) Small.				S
Eupatorium compositifolium Walt.				S
Eupatorium aromaticum L.			S	S
Mikania scandens (L.) Willd.		A		
Laciniaria gracilis (Pursh.) Kuntze.				S
Solidago Chapmanii T. & G.				S
Sericocarpus bifoliatus (Walt.) Porter.				S
Leptilon canadense (L.) Britton				S
Pluchea petiolata Cass.	S			
Gnaphalium spathulatum Lam.	S			
Gnaphalium purpureum L.	S			
Bidens pilosa L.				A
Bidens bipinnata L.		S		
Erechtites hieracifolia (L.) Raf.	S			
Cichoriaceae:				
Hieracium Gronovii L.		S	S	S
Mulgedium floridanum (L.) DC.		S	S	M

groups of *Viburnum* and *Prunus*. The wide variation of leaf sizes and shapes of *V. rufidulum* present material for speculation. Several specimens have such large leaves that they simulate the appearance of cultivated pear trees, while the remainder have leaves about half as large. Another observation that can be made after the conclusion of the trip is that the composite population lies in this zone, a fact that leads one to decide that it is due to an invasion from the surrounding pineland.

Zone 2

The most frequented path of descent starts at a point where one leaps over a large fallen oak and proceeds to tumble down the steep incline of Zone 2 to the encircling ledge, struggling to maintain a foothold by planting the feet in exposed roots and by clutching tree trunks. It proves to be a sporting venture immediately after a shower, since there is enough clay in the soil to make the path slippery. Other paths (Fig. 2) meander downward at several points on the upper slope.

The forest floor of this area is heavily carpeted with *Dryopteris normalis*[5] and *D. floridana*. It is difficult to draw conclusions about their choice for light and shade. Their dense growth in Zone 2 occurs on the south side where there is very little opportunity for receiving any direct sunlight. The predominant shrub of this zone is *Euonymus americanus*, which droops its long spreading stems over the water courses in company with the fern, *Pycnodoria cretica*. Of the trees, the two ironwoods, *Carpinus caroliniana* and *Ostrya virginiana*, together with the flowering dogwood, *Cynoxylon floridum*, appear to be predominant. Another outstanding plant is the bullace or muscadine grape, *Muscadinia rotundifolia*. Some of them are old, yet still vigorous individuals with stems as much as six inches in diameter at the base. One stem of this species, arising at the base of the cliff on the north side, clambers up a tree on the upper level of the sink. Judging by the tracks on the cliff, this has been used frequently as a living rope ladder for the elevation of the more agile visitors to the Millhopper. There are several fine specimens of sweet gum, *Liquidambar styraciflua* in this zone, one of which stands on the ledge on the south side (Fig. 3). It measures 10 feet 3 inches in circumference at a point 3 feet from the ground. The presence of this specimen growing so far below the elevation of the surrounding territory is another reason for geologists to believe that this limesink is quite old. Another specimen of remarkable proportions growing in this zone is an example of *Pinus glabra*, having a circumference of 7 feet 8 inches, which may be noted on the southeast bank near the ledge. One specimen of *Quercus virginiana*, whose limbs are covered with *Polypodium polypodioides*, grows in the rich soil of the ledge on the north side of this zone within the *Rhapidophyllum Hystrix* association that was burned in the spring of 1933. Its trunk measured 5 feet 9 inches in circumference at a height of 3 feet from the ground. One excellent specimen of *Q. Prinus* growing in a similar situation on the southeast side of this zone has a trunk that measures 8 feet 7 inches in circumference at the same point of measurement. All of these observations serve to substantiate the theory that the first cave-in may have extended to the ledge and thus have formed the original sink.

Zone 3

After reconnoitering the ledge, two paths of descent to the bottom are observed. The first is located close in line with the path from the

[5] Nomenclature of Pteridophyta follows: Small, John K. Ferns of Florida. 237 pp. 107 illus. Science Press. 1931.

top and tumbles down alongside of a small gully washed from a spring (Fig. 4). In very wet weather it is impassable on account of steepness and the character of the soil, which is composed largely of clay and fuller's earth at this point. The easier means of descent is a path reached after walking a hundred years or so to the west around the ledge. The end of the path lies at the foot of a tree stump located on a bank which is above water level when the pool is filled.

In Zone 3 there is a special point of interest in a large *Dryopteris* colony (Fig. 5) growing on the bank having a southern exposure, where it has the advantage of direct sunlight and little competition, since there is an absence of perennials. Apparently, there has been a slide here in some not far distant time. This *Dryopteris*-covered slide is one of the paths of descent to the bottom, which is further accomplished by grasping the tough and tenacious fronds and sliding along. On arrival at the bottom of the cruise, one's feet land in oozing ground bearing large elderberry bushes and blackberry vines, while the floor is thickly populated with *Viola sororia*, which thrives prodigiously in this environment. As early as the last of January the inner periphery of this zone on the north side is a solid mass of pale violet blue. On the lower banks in moist locations, *Solanum gracile* has abandoned its upright habit of growth and droops long branches several feet toward the declivity.

Zone 4

Ideal conditions obtain in this zone for the establishment of a pioneer flora and many such plants have appeared during these years of drought. When the bottom became exposed, a small colony of *Salix longipes* sprang up in the mud. A few plants of *Saururus cernuus* appeared suddenly and also a small whip of *Cephalanthus occidentalis*, hydrophytic plants that are not found among the semi-xerophytic associations in the surrounding territory. On the western side at the foot of the largest waterfall, there is a heavy growth of the violet, *V. sororia*, previously discussed, while not far distant from this colony there is a thick mat of *Dichondra carolinensis*. Among the straggling specimens of *Iresine Celosia*, *Persicaria hydropiperoides*, *P. setacea*, and *Pluchea petiolata* are wound the stems of the twining plant *Valeriana scandens*.

Predominant in this association are the sedges and grasses (Fig. 6) with two species of *Carex* in preponderance. Great rank stems topped by the puffy bracts that characterize *C. lupulina* are intermingled with plants of *C. stipata*. Along the edges of the drainage streams are

growing *Adicea pumila* and straggling specimens of several species of *Physalis*, while in the streams themselves are *Radicula Walteri*, bishops weed, *Ptilimnium capillaceum*, and *Samolus floribundus*.

SUMMARY

A study of the more conspicuous flora of the Devil's Millhopper, a lime sink located six miles northwest of Gainesville, Florida, reveals that there are 160 species of Pteridophyta and Spermatophyta represented by 70 families of 38 orders.

Ecologically there are three plant associations in the form of circular zones here. The first is a semi-mesophytic association of plants that prefer the dry sand of the periphery of the sink among which certain viburnums and composites are typical; the second is the hardwood hammock association growing on the calcareous soils of the steep banks in which *Dryopteris* and *Quercus* predominate; and the third is the grass-sedge association which has developed on the alluvial soil of the recently exposed bottom.

Not only the topographical features, but also moisture and light are governing factors in the delimitation of these associations. The less mesophytic association on the periphery of the sink receives plenty of light, but suffers from excessive drainage due to the proximity of the steep walls of the depression. The hardwood hammock association receives the benefit of plenty of moisture from the seepage streams running in from all sides, yet the competition for light is very keen. The grass-sedge association responds luxuriantly to a generous supply of sunlight and moisture on the rich alluvial substratum.

Inasmuch as the type of vegetation in any given area is influenced primarily by the topography, the changing conditions at this station continually interfere with normal succession and practically preclude the attainment of a climax flora.

The writer wishes to acknowledge the assistance of Mr. David G. A. Kelbert in making the photographs.

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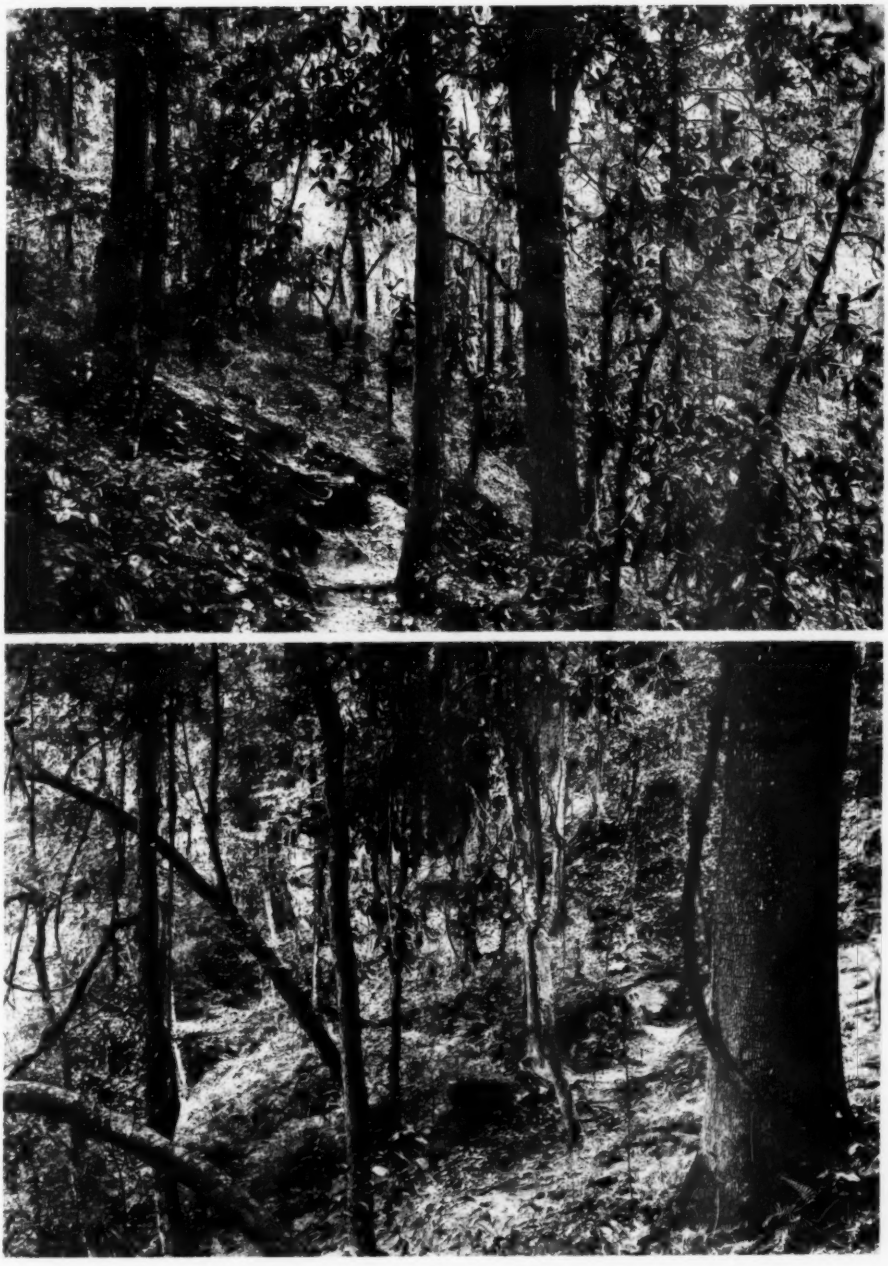

FIG. 2 (ABOVE). TYPICAL HARDWOOD VEGETATION IN THE DEVIL'S MILLHOPPER ALONG ONE PATH OF DESCENT IN ZONE 2

FIG. 3 (BELOW). VIEW OF LEDGE SHOWING FINE SPECIMEN OF LIQUIDAMBAR STYRACIFLUA WHICH STANDS ON THE SOUTH SIDE OF ZONE 2

PLATE 8

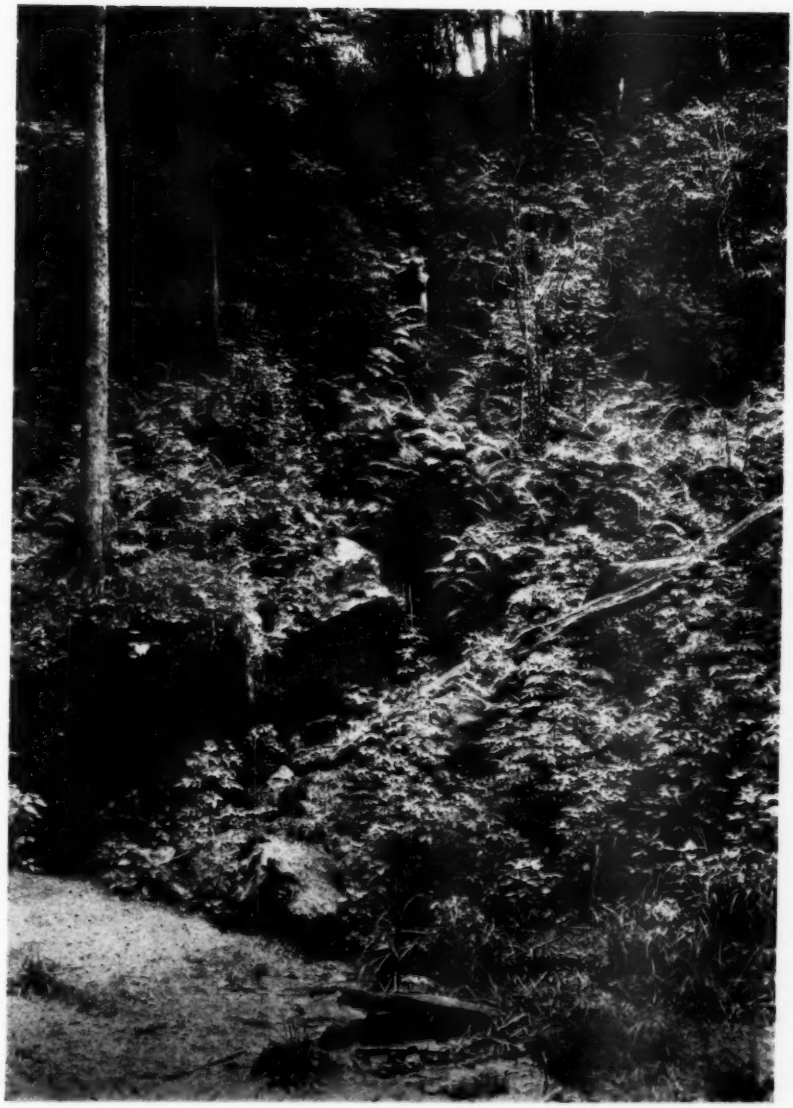

FIG. 4. DEVIL'S MILLHOPPER. VIEW SHOWING TYPE OF VEGETATION GROWING ON THE SOUTH SIDE OF ZONE 3

The course of a seepage stream terminates in an underground outlet at the foot of the rock in the foreground.

PLATE 9

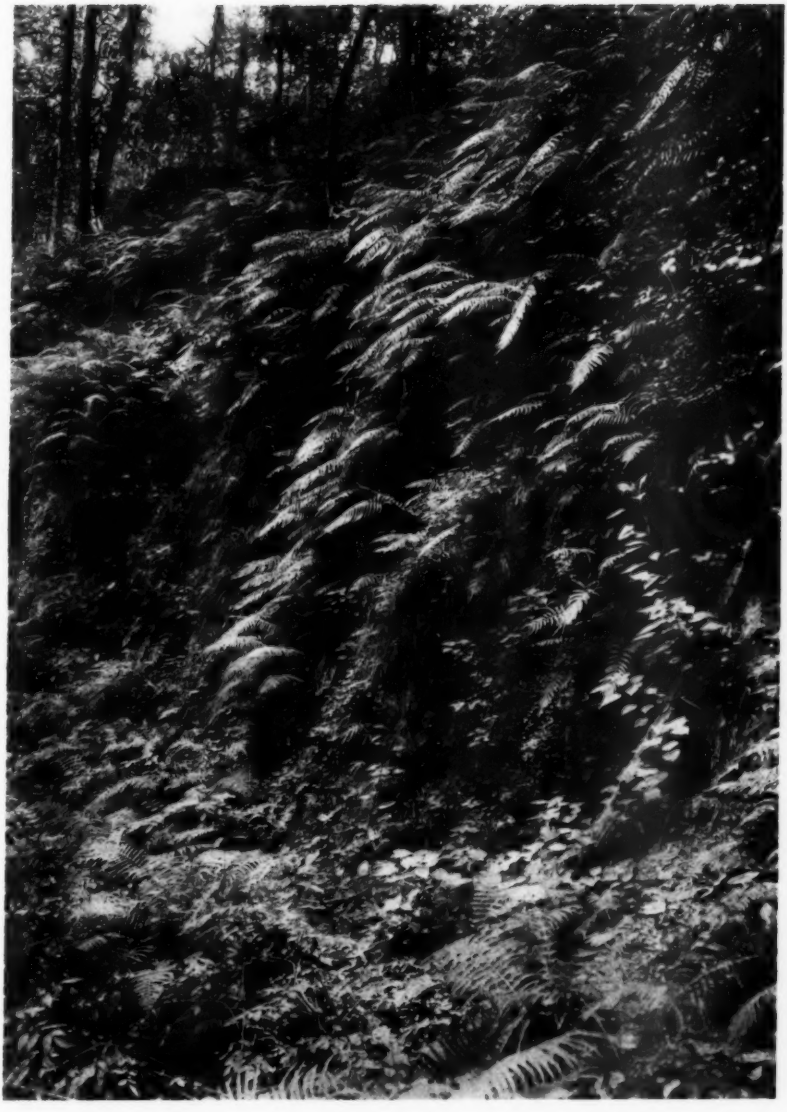

FIG. 5. DEVIL'S MILLHOPPER. VIEW OF A COLONY OF DRYOPTERIS NORMALIS GROWING IN DIRECT SUNLIGHT ON THE NORTH SIDE OF ZONE 3

PLATE 10

FIG. 6. VIEW OF THE GRASS-SEDGE POPULATION OF ZONE 4 MAY BE SEEN IN THE FOREGROUND

EPIDENDRUM CONOPSEUM IN NORTH CAROLINA

By Donovan S. Correll

Plate 11

Epidendrum conopseum R. Br. was reported for the first time from North Carolina by Thomas F. Wood and Gerald McCarthy in their *Wilmington Flora*, published in the *Journal of the Elisha Mitchell Scientific Society*, vol. 3, 1885–86. Credit is here given to a Major Young as having found it in Pender County in 1881. As far as the writer has been able to determine, there is no other record of this orchid having been found in the state until 1933 when Small included North Carolina in its (*Amphiglottis conopsea* (Ait.) Small) range in his *Manual of the Southeastern Flora*.

It is interesting to know that for a period of 46 years this orchid has evidently escaped collectors in North Carolina. In a conversation with Professor Oakes Ames last winter he expressed the opinion that the reason for this was perhaps due to the "Big Freeze" of 1888–89 which may have destroyed these plants this far north and thus temporarily moved the limits of its northern range farther south. It is also possible that the position of the orchid high up in the trees may have made it easily overlooked.

While collecting in the eastern part of the state last summer, much time was spent in an unsuccessful attempt to find new stations for *Epidendrum conopseum*. Not being discouraged, however, further search for this plant was made on the week-end of October 5 and 6, when Dr. H. L. Blomquist and the writer made a collecting trip through the Coastal Plain region of the state. On the return trip, a brief stop was made at Lake Waccamaw, Columbus County, to collect the Florida shield fern (*Dryopteris floridana* (Hook.) Kuntze) which reaches its northern limit there, and to look for any orchids which might be in flower at this time of the year.

After having found a few beautiful specimens of *Spiranthes odorata* (Nutt.) Lindl. in full bloom, growing in the flooded, mucky soil of a swamp on the northwestern side of the lake, we walked a short distance along a narrow, wooded sandbar, lying between the lake and the flooded swamp. Suddenly Dr. Blomquist called our attention to a large limb

of a sweet gum tree, growing out about 15 feet from the base of the trunk of the tree and arching out over the sandbar to about 8 feet from the ground. With that astonishment and delight experienced only by searching botanists, we saw growing on a considerable part of the limb a mantle of *Epidendrum conopseum* together with the epiphytic fern *Polypodium polypodioides* (L.) Watt. Needless to say, there was a clambering up the branch in a flash. At last, after many weeks of vain search and disappointments, here was success!

In spite of the inclement weather, the late hour of the day, the difficult position of the plant, and a single film left, we succeeded in obtaining a fairly respectable photograph of the orchid, which is reproduced herewith.

After returning home, we communicated with Dr. J. K. Small who kindly informed us that his report was based on a specimen collected by Mr. H. A. Rankin of Fayetteville, near Hallsboro, Columbus County. In response to a letter to Mr. Rankin, we have received a specimen from him with the following note: "We were cutting timber in White Marsh, a large swamp between Hallsboro and Whiteville (Columbus County), along the railroad crossing. On practically all of these large tupelo trees there were large colonies, growing just like *Polypodium* and frequently with this. All was high in the trees—from 40 to 60 feet—and usually about the large limbs where the main trunk divided. Sometimes they would cover sections four to six feet long."

Apparently this orchid is fairly common in the Lake Waccamaw section and possibly in other places in the southeastern part of the state, although, so far as known, only two collections exist which are represented by specimens.

It may be of interest to add that collections of *Epidendrum conopseum* have also been made in the neighboring state of South Carolina. Dr. W. C. Coker of the University of North Carolina collected the orchid from a large limb of live oak at Myrtle Beach on July 13, 1932, and H. W. Ravenel collected it along Santee Canal where he said it was growing as a "parasite on *Acer rubrum*." There may possibly be some other collections from South Carolina which have escaped our notice.

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PLATE 11

EPIDENDRUM CONOPSEUM AT LAKE WACCAMAW, N. C.

NEW AND LITTLE KNOWN ALGAE FROM NORTH CAROLINA

By L. A. Whitford

Plate 12

For several years the writer has been collecting freshwater algae in the piedmont and coastal plain of North Carolina. Among the more than 360 species and varieties identified from these collections is a number of species either new, or rare and little known. Of the species listed below one is undoubtedly new, two are new to the United States and the others are very rare or have been collected only a few times in this country.

The dimensions are given for each species as well as the months and places of collection. Other states in which the various species have been collected are given. Descriptions or emended descriptions are given for several and six are figured.

The author wishes to acknowledge the helpful criticism of this work by Dr. L. H. Tiffany of Ohio State University.

CHRYSOPHYCEAE

Chrysomonadales

Chrysosphaerella longispina Lauterborn.

Average cells 9μ in diameter, 15μ long, spines 19–39μ long. Colonies 50–250μ in diameter. In North Carolina collections the colonies are small (47–58μ).

From 3 ponds, Cumberland County. May. Also in Wisconsin and New York.

Relatively abundant in Cottonade and Lakewood ponds.

Synura adamsii G. M. Smith.

Cells 7.5μ in diameter, 39–50μ long. Colony 78–93μ.

From a swamp and several ponds, Cumberland County. May. Also in Wisconsin and Iowa.

The long narrow cells are loosely joined at the center of the colony and oscillate as the colony rolls slowly over.

CHLOROPHYCEAE

Volvocales

Pandorina charkowiensis Korshik. Fig. 1.

Cells 10–15μ in diameter. Colony 43–68μ × 58–88μ. The colonies in North Carolina collections average smaller (50μ × 65μ).

Plankton, Neuse and Trent Rivers and Core Creek, Craven County. June and September. Also in California.

The ribs on the chloroplast are obscure and most easily seen in freshly collected specimens. Red eye-spots were not observed.

Ulotrichales

Basicladia chelonum (Collins) Hoffm. and Tilden.

Basal cells 12–35μ in diameter, 680–1360μ long, other cells 27–50μ × 58–156μ. North Carolina specimens are slightly larger than the average.

Attached to a small turtle, White Lake, Bladen County. May. Also in Michigan, Iowa, Massachusetts, and Ohio.

Upright branches arise from a corraloid basal system. Lower branches remain nearly parallel to the main branch but the occasional upper branches digress at nearly right angles. Several cells were filled with zoospores or gametes and some were escaping through a pore in the wall.

Oedogoniales

Oedogonium nebraskense Ohashi.

Cells 20–27μ in diameter, 57–230μ long; oogonia 60–67μ × 70–79μ; oospores 53–64μ × 60–76μ. In North Carolina specimens the oogonium is larger (74–78μ × 105–109μ) and the oospores average 60μ × 70μ.

Lake Raleigh, Wake County. April 15, 1935.

This seems to be the first recorded collection of this species in America after it was described from a collection made in Lincoln, Nebraska, April 22, 1919. Note that in spite of the difference in latitude and climate both the collections were made in mid-April

Chlorococcales

Pachycladon umbrinus G. M. Smith.

Cell without processes 8.5μ × 15.5μ; processes 35–50μ long.

Apex city reservoir, Wake County. May. Also in New York and Ohio.

The cells were typical but rare in the plankton.

Tetraedron quadricuspidatum (Reinsch) Hansgirg. Fig. 2.

Cell without spines 36μ in diameter, 50μ long. North Carolina specimens average slightly longer and narrower than the type.

Carolina Pines Pond and a small pond near Swift Creek, Wake County. October.

About half the cells observed had only 3 spines but were otherwise typical.

Tetrallantos lagerheimii Teiling.

In the North Carolina collection the cells are 4μ in diameter, 15μ long. Colony 35μ.

Plankton, Cumberland Pond No. 2, Cumberland County. May. Also in Wisconsin and Mississippi.

There is a definite yellowish envelope. The cells are arranged in the characteristic way and attached by cellulose (?) processes.

Siphonales

Vaucheriopsis arrhyncha (Heidinger) Heering. Figs. 3, 4.

Filaments 100μ in diameter, oospores 150μ. In the North Carolina specimens, filaments 87–115μ; oogonia 155–164μ × 164–170μ; antheridia 35μ in diameter 77μ long; pedicels 341–429μ long.

The original description should be emended to read *oil droplets present in filaments and spores.*

Ditch, State College orchard, Wake County. Apr.-May. This appears to be the first collection of this species since it was described from Freiburg, Germany, in 1908.

Tests with the fat stains Sudan III, Scralet R, and with osmic acid show oil droplets to be present in filaments and spores. Pedicels with one oogonium are more abundant than those with two. Sex organs occasionally are produced at the ends of filaments. Otherwise the material seems entirely typical.

Zygnematales

Phymatodocis nordstediana Wolle. Fig. 5.

In the North Carolina collections the cells are 55–62μ in diameter, 43–47μ long.

Dividing cells indicate that the described method of cell division is correct and therefore different from that in *Desmidium.*

From a sand pit, Lillington, Harnett County, in May and Partin's Mill pond, September, 1935. Also in New Jersey.

This rare Desmid has been reported only twice from this country, and not since 1895. It may be less rare than previous collections indicate.

In both collections it was present in the plankton and relatively few plankton collections have been made in the South Atlantic coastal plain.

DINOPHYCEAE

Peridinium wisconsinense Eddy.

Cells 48–56μ in diameter, 55–64μ long.

Bladen County. May. Lake Raleigh, Wake County. April and October. Also in Wisconsin and Minnesota.

This speeies was relatively abundant in the plankton of several ponds.

Ceratium curvirostre Huitfeldt-Kass. Figs. 6 and 7.

(*Peridinium carolinianum* Bailey)

Cells 55–103μ in diameter at the groove, 156μ long. North Carolina specimens are 66–78μ in diameter and 129–154μ long.

The apical horn is short, curved sharply to the right, and always pointed. There are two antapical horns one longer and stouter than the other. In some cases at least the protoplast escapes from the mother-cell wall before division and each daughter cell develops an entirely new wall. (Fig. 6.)

Plankton of coastal plain ponds. May to October.

The writer agrees with Pascher in regarding the above a valid species and not merely an ecological variation of *C. hirundinella* (O. F. Muller) Schrank. Both species have been collected in abundance in numerous streams and ponds in the lower piedmont and eastern North Carolina. In one pond both were present and there were no intergrading forms. In a number of other cases the two have been collected the same day from different ponds of almost identically the same size and conditions and but a few miles apart. *C. hirundinella* seems to be the form *rubustum*. It sometimes has only two antapical horns but the apical horn is invariably long, straight and truncate. The general appearance is consistently different, as shown by the figures. *C. curvirostre* is rare in the piedmont but *C. hirundinella* has been collected throughout the eastern half of the piedmont and the coastal plain. (Figs. 6, 7, and 8.)

EUGLENOPHYCEAE

Trachelomonas lolliensis sp. nov. Figs. 9 and 10.

Lorica ellipsoidal, converging rather sharply at the anterior end into a long collar and at the opposite end into a posterior process. Surface granulate, studded with stout pointed spines. Color brownish yellow. Collar elongate-cylindric, terminal margin bearing 5 or 6

pointed, divergent spines. One or two lateral spines. Posterior process hollow, nearly identical with collar but slightly conic. Usually with one or two lateral spines. Three or four somewhat divergent spines at end.

Cells without spines 5–11μ in diameter, total length 35–40μ. Collar 5–11μ in diameter 12μ long. Posterior process 4–8μ in diameter 12μ long. Body spines 3–5μ long.

Apex city reservoir. May, 1935.

The organism swims with a slow rolling motion.

It was rare at the time collected and was not present in a collection made at the reservoir in October, 1935. Collection of the writer No. 284.

STATE COLLEGE OF AGRICULTURE
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EXPLANATION OF PLATE 12

All drawings were made with the aid of a camera lucida. Cells in Figs. 6, 7, and 8 drawn in outline only.

FIG. 1. *Pandorina charkowiensis* Korshik. ×425.

Fig. 2. *Tetraedron quadricuspidatum* (Reinsch) Hansgirg. ×500.

Fig. 3. *Vaucheriopsis arrhyncha*. (Heidinger) Heering. Fruiting branch with mature oospore. ×150.

Fig. 4. *Vaucheriopsis arrhyncha*. Showing clumping of chloroplasts in antheridium. ×150.

Fig. 5. *Phymatodocis nordstediana* Wolle. Showing cell division and end view of cell with chloroplast. ×310.

Fig. 6. *Ceratium curvirostre*. Daughter cells with complete new walls and part of mother-cell wall. ×325.

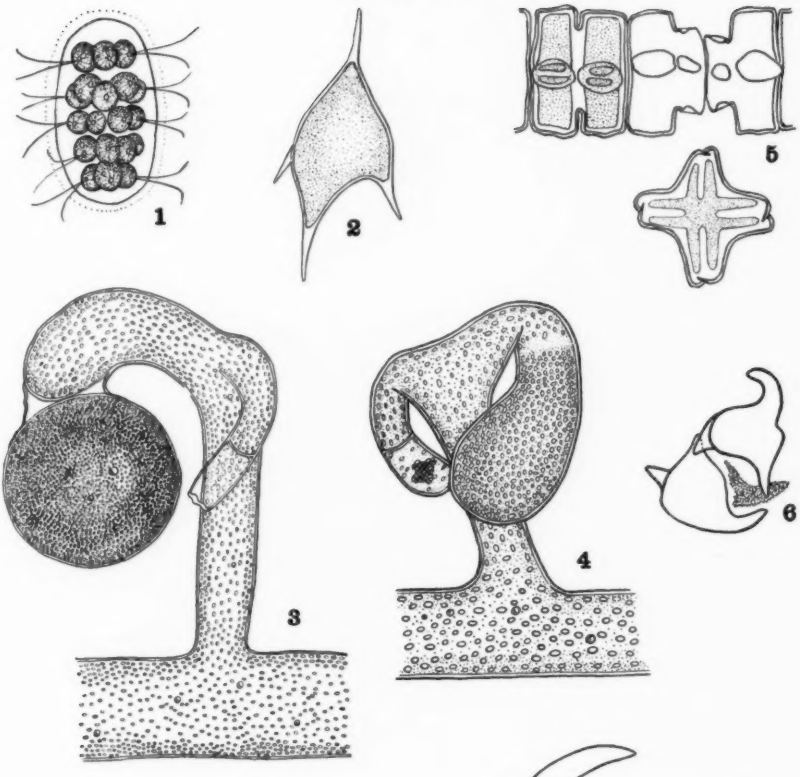
Fig. 7. *Ceratium curvirostre* Huitfeldt-Kass. From Partin's mill pond. ×280.

Fig. 8. *Ceratium hirundinella* (O. F. M.) Schrank. From same collection as Fig. 7. ×280.

Fig. 9. *Trachelomonas lolliensis* sp. nov. ×1180.

Fig. 10. *Trachelomonas lolliensis*. Optical section. ×1180.

PLATE 12



THE PRODUCTION OF MATURE PERITHECIA OF CORDYCEPS MILITARIS (LINN.) LINK IN LABORATORY CULTURE

By Leland Shanor

Plate 13

De Bary (1) in 1867 was able to get the production of perithecia of *Cordyceps militaris* (Linn.) Link in his laboratory, but was never able to get these fruit bodies to produce the mature asci. In only one case was he able to obtain even immature perithecia and these were borne on an abnormal fruit body.

The descriptions and discussions of this fungus by Tulasne (4) and others, as far as I have been able to find, were made from specimens collected in nature. They did not attempt to carry on any culture work. Pettit (3), in 1895, attempted to obtain in culture the production of the perfect stage of this fungus and others of its genus, but without success. Varitchak (5), in 1927, used material collected in nature to carry out his cytological studies.

The authors of the more recent textbooks on mycology make no mention of the work of de Bary on the attempt to obtain the production of mature perithecia of *Cordyceps militaris*. The following report appears, therefore, to be the first to describe the growth of any species of *Cordyceps* from spore to spore in the laboratory.

Specimens of *Cordyceps militaris* were brought into the laboratory by a student on October 10, 1935. These were growing on the pupae of some small Lepidoptera. They were at that time identified and checked with specimens in the herbarium. They were then placed in a petri dish on filter paper and allowed to dry.

Upon finding that this fungus had not been cultured to maturity, an attempt was made to induce the germination of the spores and to get the fungus in culture. A pupa bearing the stromata was placed in a moist chamber and soon normal "puffing" of spores began. To get spores free from contamination, they were taken from the ostioles of the perithecia by touching them with a sterile needle and then transferring them to a petri dish containing a sterile malt extract agar (20 gms. malt extract, 15 gms. agar, 500 c.c. distilled water). This planting

of the spores was done on October 23, and two days later the spores had germinated and had produced minute, white, cottony masses of hyphae that were scarcely visible to the unaided eye. Five days later the colonies were over a centimeter in diameter and now hyphae were cut out and transferred from these to tubes containing some of the same culture media. These cottony cultures remained white for three weeks or a month and then began to change to a lemon color, later becoming a deep orange. In the test tubes where the mycelium pressed against the side of the tubes, it presented a reddish color (fig. 1). This growth of hyphae produced condiospores abundantly which were borne on elongated, awl-shaped sterigmata. These sterigmata may be either terminal or lateral and when they are lateral may be borne singly or in whorls around the hypha. These conidiophores agree with those described and figured by de Bary (1) and Pettit (3). The conidiospores germinated readily when placed on the malt agar culture media. In places on the surface of the cultures in test tubes the hyphae would sometimes cluster together, rising above the rest of the culture forming a coremium. However, these bore only conidiospores, there being no indication of perithecia-bearing fruitbodies ever produced on this culture media.

On September 28, a larva of the Imperial Moth, *Basilona imperialis* Drury, was collected and brought into the laboratory to metamorphose. It was fed constantly with fresh leaves until the time of pupation on October 12. This pupa was now laid aside in a container on dry filter paper and was still quite lively on November 19, when it was inoculated with hyphae from my cultures. This was done by placing a few of the hyphae into the body of the pupa with a sterile needle. The pupa was now placed in a moist chamber and kept damp with filter paper. On the third and fourth days after this operation the pupa showed less signs of life and was found to be dead on the fifth day. Parts of its body had collapsed, noticeably the wing and antennae cases. The pupa now was converted into a sclerotium by the growth of the fungus. A section of its body later showed that almost all of the soft internal parts had been digested by the fungus.

On December 13, orange colored clusters of hyphae began to push out of the body through the spiracles and at thin places on the abdomen. These continued to grow until, by December 23, they were over a centimeter long. They now ceased to develop further, but produced white, conidia-bearing hyphae. These may have been the Isarial stage, but they do not agree with the description of the *Isaria farinosa* Fr. described by Tulasne (4) as the imperfect stage of *Cordyceps militaris*.

No further development took place until about January 6, 1936, when another knob-like projection made its appearance. By January 13, it had grown to a length of two centimeters and the shape of this body was that of the typical *Cordyceps* fructification. The whole surface of this fruit body was covered smoothly with orange colored hyphae and as yet no indications of the appearance of perithecia were seen. Growth continued, and by January 20, this body had reached a length of over three centimeters. This was somewhat larger than the parent fruit bodies, but the greater amount of nourishment present now might explain this. This pupa was much larger than the one on which the original fructifications were found. Upon examining this fruit body with binoculars, it was found that small dark spots appeared scattered thickly among the hyphae from about midway from its base to its tip. Upon pushing the hyphae back from one of these with a needle, it was found to be the ostiole of a developing perithecium. On January 21, one of these perithecia was removed and examined with the compound microscope. Ascogenous cells were abundant and hook processes were quite numerous. For a couple of days more the development continued and the perithecia became more prominent as the downy hyphae enveloping them collapsed. Development now ceased and over the whole surface of the fruit body downy, white, conidia-bearing hyphae appeared. This suggested that some deficiency in the growing environment preventing further development must exist. Therefore, other experiments were begun.

I had by this time received a supply of the pupae of a common moth, *Callosamia promethia* Drury, from my brother from Butler, Pennsylvania. The following experiments were carried out on these (figs. 2 and 3).

Six pupae were inoculated while still alive, as was done in the first experiment, and then placed in sterile test tubes to be observed until it was certain that they were killed by the fungus. Four were then placed in a sterile container in moist, autoclaved Sphagnum moss. The other two were each placed in a small Erlenmeyer flask and kept moist with filter paper.

Still two other pupae were autoclaved and then inoculated in the same manner as was done with the others. When the fungus had become thoroughly established, one of these was placed in a container in moist, sterile Sphagnum and the other was placed in a small flask to be kept constantly moist with damp filter paper.

All of the cultures made on the living pupae developed at about the same rate as had occurred in the first experiment. Those in the Sphag-

num, however, developed a little faster. Those grown in the flasks ceased development after the production of young perithecia and produced the white, conidia-bearing hyphae as had occurred in the first case. Those cultures in the Sphagnum went on to produce mature perithecia and liberated spores as freely as do fructifications found in nature. This period of development from the inoculation of the pupa until mature fruit bodies had been produced and the "puffing" of the spores was observed varies from 45 to 60 days. After the spores had been mostly liberated, the production of the white, conidia-bearing hyphae took place all over the surface of the fructification when the cultures were kept thoroughly damp.

Those cultures made after the pupae were autoclaved failed to produce anything more than thickly matted clusters of conidia-bearing hyphae. The hyphae in the cultures kept in the Sphagnum remained white, a characteristic found by Pettit (3) to occur in cultures kept in the dark. Those cultures kept in the flask showed a thick mass of oddly-clustered groups of orange colored hyphae (fig. 4). No initials of perithecia-bearing fructifications were noted in either case.

This experiment to secure the development of normal, mature fruit-bodies has been repeated several times, and each time pupae inoculated when living and then placed in the moist, sterile Sphagnum have produced perithecia containing asci with mature spores. When a single fruit body was produced on a pupa, this stroma was considerably larger than any of those produced on a pupa bearing several. The large one may attain a length of 7 cm. and a breadth of 8 mm. The largest of those produced when several arise from a single pupa was 4½ cm. long and 4 mm. wide at its broadest point (figs. 5, 6, and 7). All of these were considerably larger than the parent fruit bodies found growing on a much smaller pupa.

Attempts to obtain the production of perithecia on such media as malt extract agar and media rich in protein content as: fat pork, lean pork, lean beef, egg yolk, egg albumin, or an agar media made from the substance obtained from boiled pupae have all been unsuccessful. The fungus grows quite rapidly on all of these culture media except the fat pork and produces a dense mat of hyphae all over the surface of the media. However, only conidia-bearing hyphae have ever been produced on any of these.

Further experiments are in progress to determine how infection occurs in nature; conditions which control the production of fruit bodies; the host range of the fungus; and also its cytological development.

SUMMARY

1. The mature perithecia of *Cordyceps militaris* (Linn.) Link, borne on normal fruit bodies, were obtained in laboratory culture for the first time.

2. Live Lepidopteran pupae when inoculated and placed in moist, sterile Sphagnum moss have been found to produce normal, mature fruit bodies consistently.

3. Perithecia-bearing stromata of *Cordyceps militaris* are not produced on pupae that have been autoclaved before the inoculations were made, even if placed in moist, sterile Sphagnum.

4. No initials even of the perfect stage of *Cordyceps militaris* have been obtained on various culture media, although those media were rich in protein content.

5. The size of the fruit body varies greatly with the size of the host pupa and with the number of stroma produced on a single pupa.

ACKNOWLEDGMENTS

I wish to express my sincere appreciation to Dr. J. N. Couch, under whom this study was made, for his direction and invaluable suggestions during the course of this study. I wish to thank Dr. W. C. Coker for his kindly suggestions and his interest in this study.

I also wish to acknowledge my obligation to my brother, Donald, for sending me a good supply of the pupae of *Callosamia promethia* upon which these experiments were carried out; and to Mr. Don Ritchie for assistance in checking the literature; and to Mr. J. R. Raper for his assistance in the preparation of the photographs.

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CHAPEL HILL, N. C.

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EXPLANATION OF PLATE 13

Fig. 1. The growth of the mycelium of *Cordyceps militaris* produced on malt extract agar in a test tube. ×1

Fig. 2. Cocoons of the moth *Callosamia promethia* Drury. ×1

Fig. 3. Pupae of the same removed from the cocoons. ×1

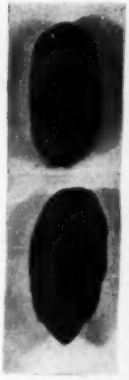
Fig. 4. The growth produced by the fungus on an autoclaved pupa that was kept constantly moist by damp filter paper in a small Erlenmeyer flask. ×1.

Fig. 5. A single large fruit body produced on an inoculated live pupa which was buried in moist, sterile Sphagnum. ×¾

Fig. 6. Three mature stromata produced on a single, inoculated, live pupa which was buried in moist, sterile Sphagnum. ×1½

Fig. 7. The same specimen as in fig. 6 after being removed from the Sphagnum and the culture container. ×1

PLATE 13



3

6

7

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5

4

A NEW AMANITA AND NOTES ON BOLETUS SUBALBELLUS

By H. C. Beardslee

Plate 14

The genus Amanita is so conspicuous and seems so thoroughly studied that the discovery of a species not only new but unique in its characters is a surprising event. This winter, however, in collecting at Altamonte Springs, Florida, we have had this experience.

Early in December a white Amanita appeared in sandy soil under pine trees, the appearance of which seemed unusual. The pileus was pure white and glabrous except for occasional closely appressed patches of the volva. The stipe was always deeply buried in the sand and was abruptly enlarged into a bulb which extended below into a well developed, pointed root 5–8 cm. long. This was quite suggestive of forms of *A. solitaria* rather than of *A. verna* with its rounded bulb. From the outer margin of the bulb the remnants of the volva extended in a loose cylinder 2–4 cm. long, not at all like the free volva of *A. verna*. The stipe itself was firm and solid and at times at least when sectioned had a distinct odor of chlorine. The solid stipe, chlorine odor, and pointed root thus seemed to suggest the *solitaria* group, while the loose volva, though unusual in its extended cylindrical form suggested rather the *phalloides* group.

The spores when examined proved to be most unusual. All of the Amanitas have spores which are either globose or very broadly ellipsoid. This species has spores as much as 15μ long and barely 4–4.5μ in diameter, being so narrowly cylindrical that they resemble nothing so much as an ordinary sausage. No Amanita known to me has spores at all similar. It has seemed best to describe this species as new, using the specific name descriptive of its spore form.

Amanita cylindrispora sp. nov.

Pileus 4–8 cm. latus, hemisphericus, demum expansus, albus, viscidus, glaber aut cum volvae fragmentis appressis, epiderme firmo, separabili. Lamellae albae, confertae, adnatae. Stipes 6–9 cm. longus, 8–10 cm. crassus, abrupte bulbosus, radice acuto 5–7 cm. longo prolongatus. Sporae cylindricae, 10–15 × 4–4.5μ. Odor chlorinatus.

In pinetis, Altamonte Springs, Florida. Dec. 1935.

Boletus subalbellus Murrill

Pileus up to 7 cm. broad, convex, rather firm, white, becoming isabelline, minutely appressed tomentose, margin thin, at first incurved; flesh white, not changing color.

Tubes white, mouths small, round, 10–14 to a centimeter (0.7–1 mm. in diameter), almost free, 5 mm. long at center.

Stipe 6–8 x 1.5–2.5 cm., stuffed, soon hollow and fragile, colored like the pileus.

Spores 10–14 x 5–6μ, hyaline under the microscope. (Caps set for spores but no good prints obtained.)

This is frequently found in lawns and open woods at Altamonte Springs. The appearance is that of a white *B. castaneus*. The spores of my plants do not coincide with Murrill's figures, but Dr. Walter Snell says they agree with the spores of the type.

ALTAMONTE SPRINGS, FLA.

PLATE 14

AMANITA CYLINDRISPORA

THE PSAMMOCHARIDAE OR SPIDER WASPS OF NORTH CAROLINA

By C. S. Brimley

Three Text Figures

The Psammocharids are vespoid wasps distinguished from related families by having the posterior angles of the pronotum prolonged backward to and beneath the tegulae, by having the first two abdominal segments not separated from each other by a constriction, and by the possession of elongate legs, the hind femora always extending beyond the middle of the abdomen, and in addition they are always smooth, never roughly sculptured.

Our species range in size from very small wasps, only 5 mm. in length to very large ones, 25 mm. long, and still larger forms occur in the southwestern United States. In color more than half our species are black or blackish without any markings whatsoever; while more than half the rest possess only restricted markings, a few only being entirely reddish or with extensive reddish or yellowish markings.

Generic and specific distinctions are based largely on the female sex, hence it is sometimes not easy to place a male with absolute certainty. In some species the sexes are alike and easily correlated; in others the opposite is the case.

The Psammocharids are active wasps and the larger species are common on flowers, having in common with many other kinds of wasps a special liking for those of Snow-on-the-Mountain (*Euphorbia marginata*). The smaller species are mostly taken by sweeping and seem less plentiful than the larger kinds, in contradiction to the usual rule among insects.

The various species dig subterranean nests which they provision with spiders as food for their grubs; those of the genus Ceropales however are parasitic on other members of the family.

An even one hundred species have been recorded from the state. Some of them however are doubtless the two sexes of species in which the sexes have not yet been correlated. This is however offset by the fact that in only one locality, Raleigh, has there been at all thorough collecting done in the family, and quite a number of other species may yet be expected from the state.

I have consulted all available literature for which see bibliography at the end of the paper, but I have found the publications on this group by Dr. Nathan Banks of the greatest help to me. Dr. Banks has also determined a number of species for us.

It should be borne in mind that all generalised statements apply only to the forms under consideration and not necessarily to extralimital species.

Keys to subfamilies and tribes, as well as to all genera and species found in the state follow and are accompanied by brief descriptions. I have seen all the species included except the following: *Pseudagenia mellipes interior* Banks, *Pseudagenia nigrella* Banks, *Episyron posterus* Fox, *Lophopompilus ilione* Banks, *Lophopompilus bengtssoni* Regan, *Pompiloides minora* Banks, and *Psammochares gracilicornis* Banks.

Of the technical terms used in this paper, most refer to the wing cells and wing veins and will be sufficiently elucidated by the figures of the three Psammocharid wings illustrated. These figures were drawn from specimens in the Collection of the Division of Entomology by Mr. D. L. Wray, a coworker in this division to whom I am greatly indebted for them.

A few other terms may need explanation. These are:

Comb. In certain females of the genus Psammochares there is a series of long spines on the outer side of the front tarsus and these are termed a "comb." In *P. fabricii* for instance there are four on the first joint (metatarsus), two on the second, and one on the third, all of nearly equal length.

Petiolate. When said of the second submarginal it means that the veins on each side of that cell coalesce above, so that the first and third submarginals are in contact above it.

Postscutellum. The small transverse piece between the scutellum and propodeum. It is now considered to be the metanotum or last segment of the thorax, while the propodeum, the apparent last segment of the thorax is now considered to be morphologically the first segment of the abdomen. As the propodeum used to be called metanotum by the older authors the use of that name is somewhat confusing and I prefer to use postscutellum.

KEY TO THE GROUPS OF PSAMMOCHARIDAE FOUND IN NORTH CAROLINA

1. Claws of hind tarsi close together and bent at right angles near the middle; labrum always visible ..... Subfamily CEROPALINAE
   Claws of hind tarsi divergent, not bent at right angles; labrum usually not exposed ..... Subfamily PSAMMOCHARINAE. 2

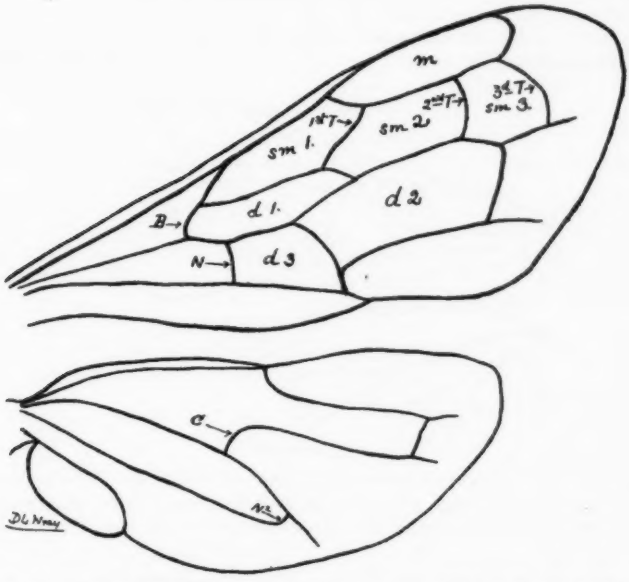

Figure 1. Wings of *Pepsis elegans*. Note three submarginal cells in front wing, no pocket at base of second discoidal cell, and that the nervulus and nervellus are well beyond the basal veins of their respective wings.

Lettering of figures

A. Cells. m. Marginal cell in front wings. (R1)
sm1, sm2, sm3. = First, second and third submarginal or cubital cells in front wings. (R. R5. R4)
d1, d2, d3. = First, second and third discoidal cells. (M4, 1st M2, M3)
B. Veins. B. = Basal vein in forewing. (m–cu)
N. = Nervulus in forewing. (M 4 × Cu1)
R1. = First recurrent vein in forewings. (M3 × 4)
R2. = Second recurrent vein in forewings. (M2)
1st T, 2d T, 3d T. = First, second and third transverse cubitals in forewings. (R5 × rm, R5, R4)
C. = Cubitus or basal vein in hind wings. (m–cu)
N1. = Nervellus in hind wing. (M3)

Note also that the vein below the submarginal cells is known as the *cubital vein*, and that between the submarginals and the marginal cell as the *radial vein*.

The Comstock equivalents of the cells and veins are given in parentheses.

2. Second discoidal cell without a pocket at its base; second ventral segment with a transverse furrow (absent in some males) . . . . . Tribe PEPSINI
Second discoidal cell with a small pocket at its base; second ventral without a transverse furrow . . . . . Tribe PSAMMOCHARINI

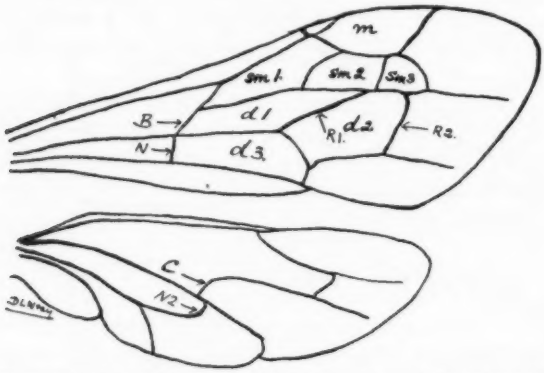

Figure 2. Wings of *Psammochares philadelphicus*. Note three submarginals, and and small pocket at base of second discoidal in front wings; nervulus interstitial with basal vein in forewings, nervellus beyond cubitus in hind wings.

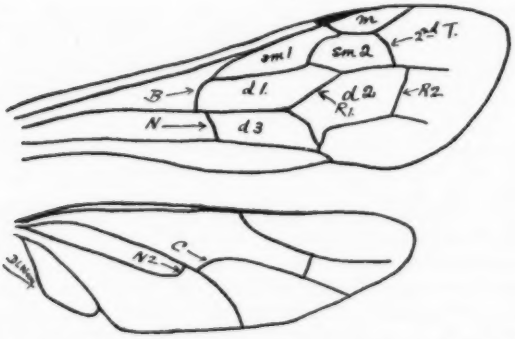

Figure 3. Wings of *Planiceps niger*. Note only two submarginals in front wings and nervellus before cubitus in hind wings.

Subfamily **Ceropalinae**

These wasps are parasitic in the nests of other species of the family. Only the type genus is found in North Carolina.

CEROPALES Latreille

The antenna is never convolute in either sex, and the body always has some pale markings. Six forms have been taken in North Carolina.

KEY TO THE NORTH CAROLINA SPECIES OF CEROPALES

1. Wings and abdomen wholly black; length about 10 mm. 2
   Wings hyaline or nearly so, abdomen with pale markings; smaller species . .3
2. Legs mainly black but with the hind femora rufous .....*bipunctatus* Say
   Legs beyond coxae entirely rufous. .....*tibialis* Banks
3. Antennae longer than head and thorax; abdomen with complete even crossbands on all or most of the segments; legs black and yellow
   fraterna Smith
   Antennae not longer than head and thorax; crossbands on abdomen interrupted or if complete, not even..... 4
4. Length about 7 mm. Crossbands of abdomen narrowly interrupted in middle; legs yellow, hind tarsi with each joint narrowly black at base
   longipes Smith
   Length 5 mm. Crossbands widely separated in middle, hind tarsi plain dusky. 5
5. Femora rufous .....*foxii* Aldrich
   Femora black. .....*katoda* Brimley

C. bipunctata Say. Length 10 mm., spread 18 mm.; abdomen usually curved under. Wings black, body black; anterior orbits white or yellowish on median half; a yellowish spot above hind coxae; hind femora rufous except at base and extreme apex. Males have in addition face below and between antennae, clypeus, labrum, underside of scape and of second antennal segment and a transverse band near apex of pronotum, white. One male has apex of front femora and whole of front tibiae rufous internally. Raleigh, Winston-Salem, Old Fort, Sept., Oct.; Bryson City, late August.

C. bipunctata tibialis Banks. Like preceding but legs wholly rufous. Greensboro, Raleigh, mid July, two males. Type locality Southern Pines, N. C.

C. fraterna Smith. Length 6–7. Female, face yellow with vertical black stripe below antennae, pronotum edged behind with yellow, a yellow spot each side on collar and another above hind coxae; broad yellow band across first abdominal segment and others at apex of remaining segments; scutel and postscutel with yellow spot and sometimes a yellow spot above mid coxae; femora mostly black, coxae black and yellow, rest of legs mainly yellow. Male similar but no black below antennae and band on first abdominal segment is divided into two broad yellow spots. Raleigh, April, May, Sept., Oct.; Laurinburg, Oct.; Highlands, Sept.; Linville Falls, June; Marion, Aug.

C. foxii Aldrich. Markings except on abdomen much as in *fraterna* but less prominent; each abdominal segment with a narrow whitish mark on each side near apex widely separated from its fellow on the other side, last segment white; legs beyond coxae rufous except hind tibiae and tarsi. Length 5. Raleigh, May, Sept., male and female.

C. hatoda Brimley. Hind legs and all femora black, otherwise as in *foxii*. Length 5. Raleigh, Sept., one male.

C. longipes Smith. Legs red except hind tarsi, the joints of which are very narrowly black at their extreme bases; pale bands on abdomen notched in front on each side, that on second segment barely interrupted. Length 6. Raleigh, June, one male.

Sub-family **Psammocharinae**

Tribe PEPSINI

Distinguished by the characters given in the key and in addition the females of the genera Priocnemis, Cryptocheilus, and Pepsis have the hind tibiae serrate behind, that is with a series of small projections each of which bears a spine. This feature however is absent or poorly developed in the males of those genera and absent in both sexes of the other genera.

KEY TO NORTH CAROLINA GENERA OF PEPSINI

1. Hind tibiae not serrate behind and without spines or with only feeble ones; nervellus not beyond cubitus in hind wing..... 2
   Hind tibiae serrate behind and with well developed spines in the females, usually with only spines in the males..... 3
2. Propodeum with erect hair above.....PSEUDAGENIA Kohl
   Propodeum without erect hair above.....AGENIELLA Banks
3. Last joint of hind tarsi without spines beneath or with only a few weak ones PRIOCNEMIS Schiodte
   Last joint of hind tarsi spined beneath, nervellus usually beyond cubitus; larger species with black wings..... 4
4. Second cubital cell usually shorter than third, receiving first recurrent vein at its middle or beyond.....CRYPTOCHEILUS Panzer
   Second cubital much longer than third, receiving first recurrent near its base PEPSIS Fabricius

AGENIELLA Banks

Small Pepsines with the hind tibiae smooth and usually without spines; propodeum without erect hair above. Ten species are on record from the state, two of which are known only in the female sex and eight only as males. The male of *Priocnemis pompilus* is included in the

key as it is practically indistinguishable from an *Ageniella* and some of the other males may also be the males of small species of *Priocnemis*.

KEY TO NORTH CAROLINA SPECIES OF AGENIELLA

1. Females with six visible abdominal segments and twelve antennal joints.... 2
   Males with seven abdominal and thirteen antennal segments..... 3
2. Wings uniformly blackish, body wholly black.....*bombycina* Cr.
   Wings hyaline cross banded with dusky, body wholly reddish....*accepta* Cr.
3. Abdomen with red on first two or three segments..... 4
   Abdomen wholly black..... 6
4. Legs except hind tibiae and four hind tarsi, yellowish red....*julia* Brimley
   Legs black..... 5
5. Tibial spurs white.....*birkmanni* Bks.
   Tibial spurs black.....*longa* Cr.
6. Legs partly reddish..... 7
   Legs wholly black..... 9
7. Pronotum edged behind with white; all the legs largely red; tibial spurs white *calcarata* Cr.
   Pronotum all black; red confined mainly to hind femora; tibial spurs black..... 8
8. Wings uniformly but faintly dusky, abdomen without a white spot at tip *aludra* Brimley
   Wings hyaline with a sharply defined dusky tip.....*adara* Brimley
9. Spurs all dark; third submarginal cell higher than wide; wings not darker at tip.....*Priocnemis pompilus* Cresson
   At least the spurs of four anterior tibiae white; third submarginal at least as long as high; wings with definite darker tips..... 10
10. All the spurs white.....*subra* Brimley
    Spurs of posterior tibiae dark.....*mintaka* Brimley

A. accepta Cr. Length 9. Raleigh, Kinston, mid June to September, on flowers especially those of *Euphorbia marginatum*. In spite of its wings it looks and acts much like a big red ant.

A. adara Brimley. Length 5. Third submarginal cell longer than high and larger than second; amount of red on hind femora very variable; front tibiae reddish. Raleigh, July to September.

A. aludra Brimley. Similar to preceding but third submarginal higher than long and smaller than second; front tibiae black. Raleigh, May, August, September.

A. birkmanni Bks. Length 5. First two or three abdominal segments red, tibial spurs white, otherwise black. Raleigh, July, August.

A. bombycina Cr. Length 10. Raleigh, May, August, November; Liberty, August. Has been bred from mud nest under bark of pine stump. This species has some spines under last joint of hind tarsi and some on hind tibiae and has been placed by Banks (1933) in a new genus *Phanagenia* Banks, type *P. osceola* Bks., Florida.

A. calcarata Cr. Length 5. Clypeus white with square black spot at base. Raleigh, April to September. Possibly the male of *Priocnemis alienatus.*

A. julia Brimley. Length 5. Besides characters given in key, it has the face and clypeus wholly black and the wings hyaline faintly tipped with dusky. Raleigh, June, one male.

A. longa Cr. Similar to *birkmanni* but the spurs are black. Raleigh, Rocky Mount, May to September.

A. mintaka Brimley. Length 5. Spurs of hind tibiae dark; in the type and only specimen the outer side of the third submarginal cell is angulated outwardly and with a short external spur. Raleigh, June.

A. subra Brimley. Similar to preceding, spurs of hind tibiae white: outer edge of third submarginal normal. Raleigh, September, two males.

PSEUDAGENIA Kohl

Similar to Ageniella but the propodeum has erect hairs on the upper surface as well as pubescence.

We have eleven species on record from the state, three represented only by males, four by females and three by both sexes and one of which I do not know the sex.

KEY TO NORTH CAROLINA SPECIES OF PSEUDAGENIA

1. First two or three abdominal segments reddish. . . . . *marionae* Brim.
   Abdomen wholly black 2
2. All three pairs of legs mainly yellowish. 3
   Legs mainly or wholly black 7
3. A black line on the inner side of each hind tibia . . . . . *mellipes interior* Bks.
   Legs wholly yellow 4
4. Females with 12 antennal joints and 6 abdominal segments 5
   Males with 13 antennal joints and 7 abdominal segments 6
5. All coxae black . . . . . *mellipes* Say.
   Four posterior coxae reddish yellow. . . . . *mellipes adjuncta* Bks.
6. Hind coxae black, rest reddish . . . . . *mellipes* Say.
   All coxae reddish yellow. . . . . *mellipes adjuncta* Bks.
7. Females with 12 antennal joints and 6 abdominal segments 8
   Males with 13 antennal joints and 7 abdominal segments 12
8. Femora largely red; coxae and four posterior tibiae and tarsi black *caerulescens* Dahlb.
   Legs wholly dark. 9
9. Front wings with a large dusky cloud on marginal, second and third submarginals and below them . . . . . *pulchripennis* Cr.
   Wings wholly hyaline. 10

10. Head and thorax black; pronotum angulate behind.....*nigrella* Bks.
Head and thorax blue or bluish.....11
11. Larger with broader face; pronotum angulate behind.....*architecta* Say
Smaller with narrower face; pronotum arcuate behind.....*nanella* Bks.
12. Front tibiae reddish, legs otherwise dark; hair of head largely white
najacra Brimley
Legs wholly black.....13
13. Hair of head mainly black.....*mariva* Brimley
Hair of head mainly white.....*nanella* Bks.

P. architecta Say. Length 7–9. Body blue with whitish hair; both second and third submarginal cells longer than high; Raleigh, May, July, September to November; Swannanoa, October, all females.

P. caerulescens Dahlb. Length 6. Fayetteville, June.

P. mariva Brimley. Length 10. Black, shining. Linville Falls, June, one male.

P. marionae Brimley. Length 7. First two or three abdominal segments largely reddish; face, scape beneath, and posterior edge pronotum whitish; flagel black. Raleigh, May, three males.

P. mellipes Say. Length 7–9. Tibial spurs usually darker than tibiae. Raleigh, Elizabeth City, Statesville, April to September, females; Mt. Mitchell, June, male.

P. mellipes adjuncta Bks. Tibial spurs light red like the tibiae; Raleigh, May to August. The male of this and the preceding have the face below and beside the antennae yellowish white and the antennae yellowish below.

P. mellipes interior Bks. Southern Pines (type locality). According to the original description the antennae are yellowish and the specimen was therefore presumably a male. I have not seen it.

P. najacra Brimley. Length 7. Front tibiae yellowish on inside and at apex, mid and hind tibial spurs reddish. Raleigh, June, male. Hickory, August, male.

P. nanella Bks. Length 6. Raleigh, May, June.

P. nigrella Bks. Black Mountain, May (Banks). I have not seen it.

P. pulchripennis Cr. Length 9. Hind tibiae with short, stout, spines. Raleigh, June, one female.

PRIOCNEMIS Schiodte

Hind tibiae serrate in female, usually not so in male; last joint of hind tarsi with few or no spines beneath. The males of the smaller species are often hard to distinguish from those of the preceding two genera.

KEY TO NORTH CAROLINA SPECIES OF PRIOCNEMIS

1. Nervellus beyond cubitus, size small 2
   Nervellus before or interstitial with cubitus 4
2. Body and legs wholly black; female ..... *nebulosus* Dahlb.
   Front and mid tarsi mostly whitish, the joints with narrow black tips; face mostly white; males 3
3. Femora black ..... *pulchrina* Cr.
   Femora rufous ..... *leibyi* Brimley
4. Abdomen with more or less red 5
   Abdomen wholly black 9
5. Size large, length 12–18; wings black 6
   Size small, length 10 or under; wings hyaline or banded 7
6. Antennae largely reddish below; hairs on hind tibiae about as long as the spines ..... *validus* Cr.
   Antennae all black; hairs on hind tibiae much shorter than the spines *gomelza* Brimley
7. Abdomen black at tip; wings banded; legs largely red ..... *alienatus* Smith
   Abdomen wholly red; wings hyaline; legs black 8
8. Pronotum arcuate behind; tibial spurs pale ..... *arcuata* Bks.
   Pronotum angulate behind; tibial spurs dark ..... *directa* Bks.
9. Wings hyaline at base, the dusky tip and a dusky band across the submarginals enclosing a subapical hyaline space ..... *germana* Cr.
   Wings not as above, practically unmarked 10
10. Propodeum transversely striate behind; wings black ..... *fortis* Cr.
    Propodeum not striate behind 11
11. Small species, length about 7 mm 12
    Larger species, length about 10 mm 13
12. Wings uniformly dusky; third submarginal cell about as high as wide *pompilus* Cr.
    Wings hyaline, dusky at tip of front wings; third submarginal decidedly longer than high ..... *agenoides* Fox
13. Face with golden pile; wings hyaline tipped with dusky; abdomen subpetiolate *fulgifrons* Cr.
    Face with black pile; wings more or less dusky with darker centers to the second and third submarginals and second discoidal 14
14. Hind tibiae with about 9 strong teeth, the spines as long as the spaces between them ..... *conicus* Say
    Hind tibiae with about 6 to 8 weaker teeth, the spines shorter than the spaces between them ..... *minorata* Bks.

P. agenoides Fox. Length about 7. Raleigh, June, August, September, three females.

P. alienatus Smith. Length 8. Wings with large subapical cloud and tip dusky. Raleigh, May, June, September; Sunburst, Linville, May; Balsam, September.

P. arcuatus Bks. Length 8. Second recurrent bent rather strongly inward before tip. Raleigh, June, one female.

P. conicus Say. Length 10–12. Wings dusky, Raleigh, February to June.

P. directa Bks. Length 8. Raleigh, June to September, females only.

P. fortis Cr. Length 12–13. Boone, Grandfather Mt., Highlands, September, three females.

P. fulgifrons Cr. Length 10. Black with much golden pile, especially on face, under side of prothorax and front coxae. Raleigh, August, one female.

P. germana Cr. Length 10. Highlands, July, one female.

P. gomelza Brimley. Length 12 (abdomen curved under). First three abdominal segments rufous above. Raleigh, April, two females.

P. leibyi Brimley. Length 7. Front coxae white anteriorly; tibiae and femora reddish; a faint cloud in second submarginal and below it. Raleigh, Tarboro, June, two males.

P. minorata Bks. Length 8. Marion, April; Spruce, May.

P. nebulosus Dahlb. Length 10. Black with dusky wings, an evident darker cloud in the second submarginal and below it, and the tip of the wing darker. Raleigh, one female.

P. pompilus Cr. Length 5–7. Raleigh, Trenton, June to October, both sexes.

P. pulchrina Cr. Much like *leibyi* but the legs are without red. Raleigh, June to August, males only. In all probability the male of *nebulosus*.

P. validus Cr. Length 19. The first three abdominal segments rufous above. Raleigh, June, July; Wilkes County, July, three females.

CRYPTOCHEILUS Panzer

Large Pepsines with the last joint of the hind tarsi furnished with spines beneath, and usually with the nervellus beyond the cubitus in the hind wings. The body is entirely black in all our species.

KEY TO NORTH CAROLINA SPECIES OF CRYPTOCHEILUS

1. Antennae mostly yellow or orange 2
   Antennae wholly black 4
2. Wings with a rather large yellow spot centering on second and third submarginal cells ..... *unifasciatus* Say
   Wings wholly black 3
3. Third ventral with a pair of humps beneath; antennae light yellow ..... *fulvicornis* Gm.
   Third ventral without humps; antennae dark yellow ..... *magnus* Cr.

4. Front wings with a large sharply defined yellow spot on outer third
maculipennis Sm.
Front wings and body wholly black: marginal cell rounded at apex
idoneus Bks.

C. fulvicornis Cr. Length, male 15–17, female 20. Raleigh, Oriental, Beaufort, Overhills, Hobucken, Kingsboro, Statesville, Winston-Salem, Marion, Judson, Cruso, Salisbury, June to October.

C. idoneus Bks. Wholly black, including wings and antennae. Length 12–15. Raleigh, Southern Pines, Laurel Hill, Winston-Salem, Marston, June to August, October.

C. maculipennis Sm. Length 23. Raleigh, July; Southern Pines, June, two females.

C. magnus Cr. Length, male 19. Judson, July; Southern Pines, Wilmington, Beaufort, June to August. I have seen only males.

C. unifasciatus Say. Length, male 13, female 20. Raleigh, Elizabeth City, Fayetteville, Swannanoa, Blantyre, Bryson City, Asheville, and Wilkes Co., July to September, both sexes.

PEPSIS Fabricius

Second submarginal longer than third and receiving first recurrent near its base. Only one species occurs in North Carolina but this is the largest member of the family and much larger forms occur in the southwestern United States.

P. elegans Lep. Wholly black with orange antennae. Length about 25 mm, spread about 40. Raleigh, Wilmington, Durham, Southport, Bryson City, Homestead, Lyons, Blowing Rock, Asheville, Wilkes County, Fayetteville, June to September.

Tribe PSAMMOCHARINI

Includes species with a small pocket at base of second discoidal cell and with the claws of the hind tarsi curved and divergent. There is no transverse groove on the second ventral and the hind tibiae are never serrate. More than half our species belong here.

KEY TO GENERA OF NORTH CAROLINA PSAMMOCHARINI

1. Pronotum long, longer than the mesonotum and much flattened above, these characters much less developed in the males. 2
Pronotum shorter than the mesonotum, arched in profile 3
2. Three submarginal cells ..... PEDINASPIS Kohl
Two submarginal cells. ..... PLANICEPS Latreille
3. Two submarginal cells. ..... APORINELLUS Banks
Three submarginal cells 4

4. Basal segment of abdomen with appressed pubescence unlike that on the following segments; claws cleft in both sexes. . . . . EPISYRON Schiodte
Basal segment without peculiar pubescence. 5
5. Labrum visible, claws cleft in both sexes, antennae of male crenulate, a distinct malar space, body, legs, and wings wholly black
ALLOCYPHONYX Ashmead
Without above combination of characters 6
6. Whole body and legs reddish or conspicuously marked with red or yellow; an impressed median longitudinal line on pronotum behind 7
At least head and prothorax black except sometimes a white posterior margin to pronotum; no such impressed line on pronotum
PSAMMOCHARES Latreille
7. Upper margin of clypeus even; whole body and legs reddish
ARACHNOPROCTONUS Ashmead
Upper margin of clypeus notched on each side; body with yellow markings; labrum exposed; antennae of male crenulate below . . . BATAZONUS Ashmead

PEDINASPIS Kohl.

Species with long flattened pronotum and three submarginal cells. The females are very distinct but the males have the pronotum shorter and less flattened and look much like the males of *Episyron* but may be distinguished by the slightly longer pronotum, the shorter joints of the tarsi, and the unequally cleft tarsal claws.

KEY TO NORTH CAROLINA PEDINASPIS

1. Females; wings blackish or banded with dusky; abdomen not wholly black . . . 2
Males; wings hyaline tipped with dusky; whole body black without markings but with appressed silvery pubescence. 4
2. Wings hyaline with dusky cross bands; head and most of body red; length 11
legatus Cr.
Wings black; length 20–25. 3
3. Thorax and abdomen mostly red. . . . . *sanguineus* Cr.
Red confined to upper surface of second abdominal segment. . *brimleyi* Malloch
4. With much long erect hair on head and body; second submarginal receiving first recurrent much beyond middle; length 11. . . . . *brimleyi* Malloch
Without long erect hair on head and body; second submarginal receiving first recurrent in middle. 5
5. Tibial spurs black; length about 10. . . . . *magnus* Bks.
Tibial spurs white; length about 6. . . . . *legatus* Cr.

P. brimleyi Mall. Black with large orange red blotch on dorsum of second abdominal segment; abdomen compressed on apical portion; second submarginal cell one and a half times as long as third or longer, narrowed more than one half above, third much shorter, about as high as long. Raleigh, Marion, Cary, Wilkes County, July to September, mostly on flowers of *Euphorbia mar-*

ginata. What I take to be the male is wholly black with much silvery sericeous pubescence and in addition with abundant long erect hair on head, body, coxae, and hind femora beneath; wings hyaline tipped with dusky. Raleigh, Beaufort, August, three males.

P. legatus Cr. The females have the body mostly red; second abdominal segment black at apex, third and fourth black at apex, white at base, fifth and sixth black; wing with outer third dusky and a dusky band across basal transverse veins, rest of wings mostly hyaline; second and third submarginals short, as high as or higher than long; legs red. Raleigh, Benson, Southern Pines, May, August. What appears to be the male has similar venation and is wholly black except for the white tibial spurs. Raleigh, June, three. The female has the habits of a female Mutillid and does not seem to fly although provided with wings.

P. magnus Bks. Much like the male of *brimleyi* but lacks the erect hair on the body; the second and third submarginal cells are about equal in size. Raleigh, June, two males.

P. sanguineus Cr. Pronotum and mesonotum orange, propodeum dark red; first abdominal segment dark red, second yellow, third yellow, black at apex, fourth to sixth black, the last two whitish at apex; head, both scutels, pleura and legs black; both second and third submarginals longer than high, subequal, second much, third little narrowed above. Raleigh, August, one female on flowers of *Euphorbia marginata*.

PLANICEPS Latreille

Similar to Pedinaspis but with only two submarginal cells in the front wings, the second recurrent meeting the cubital vein beyond the second submarginal, the third transverse cubital wanting.

P. niger Cr. Wholly black, wings of the female blackish, those of the male hyaline tipped with dusky. Length females 11–13, males, 5–8. Raleigh, Swannanoa, late May to early October. One male has only a single submarginal cell.

APORINELLUS Banks

With two submarginal cells in the front wings; pronotum short and arched in profile and both recurrents received by the second submarginal cell; propodeum with strong posterolateral angles.

A. fasciatus Smith. Mostly gray; pronotum with a subapical black

band, abdominal segments 2–4 black at base, gray at apex, wings hyaline with dusky tips. Length 6. Raleigh, Aberdeen, Carolina Beach, Marston, June, August, September, both sexes.

EPISYRON Schiodte

Medium sized or small species in which the first abdominal segment is covered with greasy looking prostrate pubescence different from that on any of the following segments; claws cleft in both sexes. Most species have a pair of pale spots at the base of the third abdominal segment which may be partly or wholly concealed when the segment is retracted.

KEY TO NORTH CAROLINA EPISYRON

1. Hind femora and tibiae rufous. ..... *posterus* Fox
   Legs without any rufous. 2
2. Spurs white; hind tibiae with a white stripe at base above; hind margin of pronotum usually white. ..... *snowi* Vier.
   Tibial spurs black. 3
3. Smaller, length 7–8; body and legs wholly black ..... *maneei* Bks.
   Larger, length 10–13; pronotum usually white-margined behind; and third abdominal segment with a pair of white spots near base; a white stripe near base of hind tibiae in male 4
4. Wings hyaline or subhyaline tipped with dusky; a pair of pale spots at base of second as well as at base of third abdominal segment; front metatarsus of female with four long spines. ..... *quinquenotatus* Say
   Wings darker, often uniformly dusky; no pale spots on second abdominal segment; only three long spines on front metatarsus of female... *biguttatus* Fabr.

E. biguttatus Fab. Variable in size and in presence or absence of white posterior border to pronotum and also in color of wings but all females have only three spines on front metatarsus and none have spots on second abdominal segment. Raleigh, Southern Pines, Elizabeth City, Wadesboro, Aberdeen, Kittrell, Swannanoa, and Bryson City, July to October, only females seen.

E. maneei Bks. Raleigh, June, August; Southern Pines, August; Fayetteville, May, all females, possibly the female of *snowi*.

E. posterus Fox. Length 7. Distinguished by the red hind legs. Beaufort, summer, 1909, one taken by Mr. Sherman, not now in our collection.

E. quinquenotatus Say. Black Mountain, mid August, two females. Two males from Bryson City in July, and Black Mountain, late May may be this or *biguttatus* as they have no spots on the second abdominal segment. Raleigh, August, one male.

E. snowi Viereck. Length 6–8. Distinguished by the white tibial spurs. Raleigh, May, June, August, September. Have seen only males.

ALLOCYPHONYX Ashmead

Wholly black species with a distinct space between the lower end of the eyes and the mandibles, the claws cleft in both sexes and the male antennae crenulate.

We have only a single species.

A. maurus Cresson. Length, males 10–15, females 15–18. Recorded from 14 localities within the state scattered from New Hanover County in the east to Buncombe County in the west and with a seasonal range from May to November. Banks described the male as *A. harpalyce* distinguishing it from the male of *maurus* by the possession of abundant silvery pile on the propodeum and both sexes by having the basal veins dislocated in the hind wings. However, all our males have the silvery pile on the propodeum and both sexes usually have the basal veins interstitial in the hind wings, consequently it seems best to consider *harpalyce* as merely a southern form of the male of *maurus*.

PSAMMOCHARES Latreille

Contains all our species of the tribe Psammocharini without sufficiently outstanding characters to be placed elsewhere.

This genus is divided into a number of subgenera any or all of which are liable in the future to be considered full genera.

KEY TO OUR SUBGENERA OF PSAMMOCHARES

1. Clypeus emarginate in front, much less so in males 2
   Clypeus not or barely emarginate in front 3
2. Pronotum angulate behind; propodeum with but little hair above
   NOTIOCHARES Banks
   Pronotum arcuate behind; propodeum densely hairy above
   LOPHOPOMPILUS Radoszowski
3. Propodeum not hairy above; small or rather small species
   POMPILOIDES Radoszowski
   Propodeum hairy above 4
4. No spines under last joint of hind tarsi; third submarginal cell not petiolate nor triangular; abdomen with red in our species
   SERICOPOMPILUS Ashmead
   Last joint of hind tarsi with spines on under side 5
5. First and third antennal joints subequal in female; pronotum almost transverse behind ..... SOPHROPOMPILUS Ashmead
   Third antennal joint plainly longer than first 6

6. No comb on front tarsus of female. ..... ANOPLIUS Lepeletier
A comb on front tarsus of female ..... PSAMMOCHARES Latreille

Subgenus NOTIOCHARES Banks

Clypeus emarginate in front, less so in males; pronotum angulate behind; propodeum only scantily hairy above. One large species belongs here.

P. (N.) philadelphicus Lep. Length, male 12–16, female 18–25. Wholly black including wings. Found throughout the state from Buncombe County eastward, flying from May to October and probably the commonest of the Psammocharids.

Subgenus LOPHOPOMPILUS Radoszowski

Clypeus emarginate in front, much less so in males; hair on upper surface of propodeum dense and the pronotum arcuate behind.

Six forms have been reported from North Carolina.

KEY TO OUR SPECIES OF LOPHOPOMPILUS

1. Wholly black species 2
Second abdominal segment largely orange above 4
2. Emargination of clypeus in female narrow and clear cut; four long spines on front metatarsus of female ..... *cleora* Banks
Emargination of female clypeus much broader and less clear cut 3
3. Emargination of female clypeus well developed; three spines on front metatarsus of female ..... *aethiops* Cresson
"Clypeus barely emarginate in front" (Banks) ..... *ilione* Banks
4. Smaller, about 10–12; pleura with little or no hair ..... *carolina* Banks
Larger, 18–20; pleura with plentiful hair 5
5. Lateral ocelli nearer to each other than to the eyes; nervulus slightly beyond basal vein, rarely interstitial ..... *atrox* Dahlbom
Lateral ocelli nearer the eyes than each other; nervulus interstitial or before basal vein ..... *bengtssoni* Regan

P. (L.) aethiops Cr. Length 17–20. Third submarginal cell much narrowed above so that it is triangular or sub-triangular. Raleigh, Statesville, June to November.

P. (L.) atrox Dahl. Length 15–20. Throughout the state, April to November.

P. (L.) bengtssoni Regan. Size of *atrox* and differs as per key. Smith Island, October, F. Sherman. I have not seen it.

P. (L.) carolina Bks. The type locality is "Black Rock," N. C., apparently a slip for Black Mountain or Blowing Rock. We have two females from Highlands, September, and Boone, summer,

1934. Have also seen one taken by Dr. T. B. Mitchell at Cruso in June.

P. (*L.*) *cleora* Bks. Length 18. Elizabeth City, August; Raleigh, June, two females.

P. (*L.*) *ilione* Bks. Length 13–15. Described from Southern Pines, N. C. Regan makes it a synonym of *aethiops*, and Banks thinks the eastern specimens referred by Regan to *cleora* are this species. I have not seen it.

Subgenus POMPILOIDES Radoszowski

Rather small species without erect hair on the propodeum. As employed here the genus includes species placed by Banks in 1917 in Nannopompilus and Arachnophila.

KEY TO NORTH CAROLINA SPECIES OF POMPILOIDES

1. Pronotum margined behind with white; males only 2
   Pronotum not margined with white 3
2. Abdomen partly red above ..... *agnema* Brimley
   Abdomen wholly black ..... *albomarginatus* Banks
3. Abdomen partly red; females only 4
   Abdomen wholly black; both sexes 8
4. Abdomen with red on first three tergites and on the corresponding sternites also 5
   Abdomen with red on tergites only; females without tarsal comb 6
5. Pronotum arcuate behind; female with comb on front tarsus *pretiosa* Banks
   Pronotum angulate behind; female without tarsal comb... *semirufus* Cresson
6. Third submarginal cell not usually petiolate; red on tergites 2 and 3 only *americanus* Beauvois
   Third submarginal normally petiolate; segment 3 usually without red. ... 7
7. Segments 1 and 2 largely red above ..... *marginatus* Say
   Red confined to second segment only ..... *reducta* Banks
8. Front tarsus of female with comb of long spines; first and third antennal joints of female subequal; third antennal joint of male short, shorter than fourth; pronotum arcuate behind ..... *argenteus* Cresson
   No comb on front tarsus of female; third joint of male antennae as long as or longer than fourth 9
9. Pronotum arcuate behind 10
   Pronotum angulate behind 11
10. Third antennal joint of female subequal to first; propodeum without longitudinal furrow ..... *minora* Banks
    Third antennal of female longer than first; propodeum with a longitudinal furrow ..... *subcylindricus* Banks
11. Third submarginal cell receiving second recurrent well beyond its middle; propodeum with longitudinal furrow ..... *insolens* Banks
    Third submarginal receiving second recurrent at middle 12

12. Third submarginal petiolate; propodeum without longitudinal furrow
cylindricus Banks
Third submarginal not petiolate, the vein between it and second submarginal straight and perpendicular to its base; propodeum with longitudinal furrow
rectus Banks

P. (*P.*) *agnema* Brimley. Length 9. Pronotum angulate behind; body with much appressed silvery pubescence; wings hyaline, dusky at tip; red confined to two spots on second tergite; third submarginal petiolate. Two males, Raleigh, July, and September. These may be males of *reducta*. A third male taken at Raleigh, August 17, 1930, has red on part of tergites 1 and 3 as well as on 2, and on the corresponding sternites also; third submarginal subtriangular, not petiolate; this may be the male of *semirufus* but is placed here for the present.

P. (*P.*) *albomarginatus* Banks. Resembles preceding but the abdomen is wholly black. Length 6–10. Raleigh, Kingsboro, June to September, seven males. Third cubital subtriangular in one, petiolate in the rest. Cannot associate this with any particular species known in the other sex.

P. (*P.*) *americanus* Beauvois. Length 10–15. Wings dusky; third submarginal usually not petiolate; red on tergites 2 and 3, not on 1. Raleigh, Kingsboro, June to early October, rather common.

P. (*P.*) *argenteus* Cresson. Length 6–8. Wings hyaline tipped with dusky; body with much appressed silvery pubescence; third submarginal subtriangular to petiolate. Distinguished by small size, arcuate pronotum, and long spines on front tarsus of female. Beaufort, one male; Raleigh, two females, six males; May, July, September.

P. (*P.*) *cylindricus* Cresson. Length 8–10. Wings dusky in females, hyaline tipped with dusky in males. Raleigh, Spruce, Highlands, May, June, September.

P. (*P.*) *insolens* Banks. Length 9. Described from Black Mountain and we have a specimen from Hendersonville (June) determined by Banks.

P. (*P.*) *marginatus* Say. Length 10–12. Averages somewhat smaller than *americanus*; third submarginal almost always petiolate and red present on tergites 1 and 2, not on 3. Raleigh, Burgaw, Wendell, Wadesboro, Highlands, May, July to September.

P. (*P.*) *minora* Banks. Described from Southern Pines. I have not seen it.

P. (*P.*) *pretiosa* Banks. Length 8. Wings dusky; first three abdominal segments reddish above and below. Raleigh, May; Hendersonville, June, two females.

P. (*P.*) *rectus* Banks. Some of the type material was from Black Mountain. Two males from Raleigh, May and September.

P. (*P.*) *reducta* Banks. Similar to *marginatus* but red on tergite 2 only and may be only a variation of that species and not the true *reducta* of Banks. Raleigh, Wilmington, Kingsboro, Pembroke, Oriental, and Marion, June to October.

P. (*P.*) *semirufus* Cresson. Raleigh, June, September, four females.

P. (*P.*) *subcylindricus* Banks. Raleigh, June, July, October, three females.

Subgenus SERICOPOMPILUS Ashmead

Marginal cell comparatively long and narrow, third submarginal long, wide above, never triangular, subtriangular or petiolate; no spines under last joint of hind tarsi; claws toothed near base in both sexes. All our species have the abdomen marked with red.

KEY TO SPECIES OF SERICOPOMPILUS

1. Mid and hind tarsi with joints largely white; pronotum margined behind with white; males ..... *cinctipes* Cresson
   No white on the tarsi or pronotum; females 2
2. Basal abdominal segments reddish above and below; legs black *fuscipennis* Lepeletier
   Abdomen wholly red, legs partly so ..... *georgiana* Banks

P. (*S.*) *cinctipes* Cr. Length 10–11. Wings whitish hyaline broadly tipped with black; joints 1–4 of mid tarsi and 2–4 of hind tarsi white tipped with black; a white stripe at base of hind tibiae above; second abdominal segment mainly red. Raleigh, Southern Pines, Jonesboro, June. Probably the male of *fuscipennis*.

P. (*S.*) *fuscipennis* Lep. Length 15. Two basal abdominal segments red; wings nearly uniform black. Wilmington, Kittyhawk, July; Raleigh, June.

P. (*S.*) *georgiana* Banks. Abdomen wholly red; hind tibiae and tars usually red. Raleigh, August; Harkers Island, June; Carolina Beach, September; Southern Pines (type locality) June, August

Subgenus SOPHROPOMPILUS Ashmead

Female with first and third antennal joints equal or the third a little the longer, and with comb on the front tarsus; pronotum usually trans-

verse behind; spines present beneath last joint of hind tarsi; third submarginal not triangular nor petiolate though much narrowed above; wings more or less dusky tipped with darker. Wholly black or bluish species of small size.

KEY TO OUR SPECIES OF SOPHROPOMPILUS

1. Pronotum angulate behind, blackish species ..... *tebemi* n. sp.
   Pronotum arcuate behind, bluish species. 2
2. Four long spines on first joint of front tarsus of female; length about 12 *ingenuus* Cresson
   Three shorter spines on first joint of front tarsus of female; length about 10 or less ..... *hyacinthinus* Cresson

P. (*S.*) *hyacinthinus* Cr. Raleigh, May, July, Aug.; Swannanoa, June.

P. (*S.*) *ingenuus* Cr. Raleigh, Aberdeen, Lumberton, Tarboro, Asheville, Swannanoa, Wendell, April, May, July to October.

P. (S.) tebemi n. sp. Length 11 mm. Black, the wings pale fuscous, the front pair broadly tipped with blackish; antennae short and thick, the third joint slightly but distinctly longer than either the first or fourth; pronotum feebly but distinctly angulate behind; propodeum with a deep groove down its dorsal surface; second and third submarginal cells subequal, the former slightly, the latter much narrowed above, each receiving a recurrent vein well beyond the middle, the second transverse cubital wanting in the right front wing; nervulus slightly beyond, nervellus slightly before the basal veins of their respective wings; marginal cell rather short and broad; only three long spines on the first joint of front tarsus; longest spur of hind tibia four-fifths its metatarsus; claws with a single tooth near base; body with very little hair.

Type, a single female taken at Smokemont, North Carolina, by Dr. T. B. Mitchell, June 30, 1934.

The short antennal joint and erect but scanty hair on propodeum place this species in Sophropompilus, while the posterior angulation of the pronotum distinguishes it from the other species of the subgenus.

Subgenus ANOPLIUS Lepeletier

Wholly black species without a comb on the front tarsus of the females and usually with dense hair on the subapical ventral segments of the males.

KEY TO NORTH CAROLINA ANOPLIUS

1. Third submarginal cell petiolate above. ..... *tenebrosus* Cresson
   Third submarginal not petiolate. 2

2. Wings nearly evenly blackish; length 10–15. ..... *illinoiensis* Robertson
   Wings nearly hyaline except at tip; length about 10. 3
3. No longitudinal groove on propodeum ..... *virginiensis* Cresson
   A median longitudinal groove on upper surface of propodeum . . *ithaca* Banks

P. (*A.*) *illinoiensis* Robertson. Length 10–15. Third submarginal much narrowed above; males with much dense hair on underside of subapical ventral segments. Both sexes from Raleigh, Wendell, Sanford, Pembroke, and Wadesboro, May to October.

P. (*A.*) *ithaca* Banks. Length 10–11. Much like *virginiensis* but wings slightly darker and there is a longitudinal groove on the upper surface of propodeum. Raleigh, April, May, three females.

P. (*A.*) *tenebrosus* Cresson. Wholly black, wings dusky. Raleigh, October; Southern Pines, March; Swannanoa, September. Length 10–15.

P. (*A.*) *virginiensis* Cresson. Length 8–10. No median longitudinal groove on propodeum. Raleigh, May, June; Moncure, October; Swannanoa, May.

Subgenus PSAMMOCHARES Latreille

Comprises species either all black or with some red on the abdomen. There is a comb of long spines on the front tarsus of the female, the third antennal joint of the female is longer than the first, there are spines beneath the last joint of the hind tarsus and erect hair on the propodeum.

KEY TO NORTH CAROLINA SPECIES OF PSAMMOCHARES

1. Abdomen partly red 2
   Abdomen wholly black 5
2. Red on abdomen mostly confined to upper surface of second segment; vertex rather wide. ..... *fabricii* Banks
   Red more extensive. 3
3. Pronotum edged with white behind, both scutella gray on the sides *autumnalis* Banks
   No white on pronotum nor gray on scutella. 4
4. Vertex narrow, narrower than in *fabricii*; spines on front tarsus of female short *eurydice* Banks
   Vertex as wide as in *fabricii* ..... *marginalis* Banks
5. Third submarginal cell triangular; length over 15; prothorax arcuate behind *relativus* Fox
   Third submarginal subtriangular or trapezoidal; length not over 15. 6
6. Pronotum arcuate behind; males with tarsal claws toothed 7
   Pronotum angulate behind; tarsal claws of males cleft. ..... *astur* Banks
7. Bluish; marginal cell rather short, acute at tip; third antennal joint of male shorter than fourth. ..... *scelestus* Cresson
   Black; marginal cell long, almost rounded at tip; third antennal joint of male longer than fourth ..... *gracilicornis* Banks

P. (*P.*) *astur* Banks. Length 10–13. Wholly black with pronotum angulate behind and third submarginal cell but little narrowed above. Raleigh, Wilmington, Pembroke, Wadesboro, Moncure, Aberdeen, Sanford, April to October; Highlands, Linville, Grandfather Mt., Swannanoa, July to October.

P. (*P.*) *autumnalis* Banks. Length 12. Black with light gray pubescence on anterior and posterior edges of pronotum, and on sides of scutella and of upper surface of propodeum; first two and base of third abdominal segments red above and beneath. Three females Oriental, June; Wilmington, May; Raleigh, May.

P. (*P.*) *eurydice* Banks. Length 12–14. Vertex plainly narrower than in *tropicus*; first, second and most of third abdominal segments reddish orange above and below; spines of tarsal comb short; third submarginal triangular. Two females, Raleigh, September; Kinston, June.

P. (*P.*) *gracilicornis* Banks. Type locality, Southern Pines, May. I have not seen it.

P. (*P.*) *marginalis* Banks. Much like *fabricii* but smaller and with red on first three abdominal segments. Type locality Southern Pines, from which place we have a female taken in August, also a pair from Aberdeen, close by, in October, and a male from Raleigh, July.

P. (*P.*) *relativus* Fox. Wholly black with pronotum arcuate and third submarginal triangular. Four females from Raleigh, July, October; Fayetteville, June; and Zebulon, September.

P. (*P.*) *scelestus* Cresson. Length 13. A single male from Kittrell in July.

P. (*P.*) *fabricii* Bks. (= *tropicus* L., preoccupied) Length 15. Black with large orange spot occupying basal three-fourths of second abdominal segment. Raleigh, Southern Pines, Aberdeen, Norlina, Faison, Castle Hayne, Wilmington, and Carolina Beach, June to October.

ARACHNOPROCTONUS Ashmead

Ferruginous species with median longitudinal groove on pronotum and upper edge of clypeus not notched. The species of this genus and the next look very much like the social wasps of the genus *Polistes*. Only one species is known to occur in the state.

A. ferrugineus Say. Length 10–20, the females much the larger. Wholly ferruginous, the propodeum darker and the legs lighter. Rather common at Raleigh, June to October, also taken at Blantyre,

Marion, Greensboro, Salisbury, Southern Pines, Oriental, and Southport.

BATAZONUS Ashmead

Ferruginous species varied with black and yellow; upper edge of clypeus notched on each side; a median longitudinal groove on the propodeum. Two species have been recorded from the state.

KEY TO NORTH CAROLINA BATAZONUS

1. Propodeum with yellow markings at its apex; mesonotum and coxae also usually with yellow markings..... *navus* Cresson
   Propodeum, mesonotum, and coxae without yellow markings. *interruptus* Say

B. interruptus Say. Much like the next but with more black and less yellow. Raleigh, two males, June and July.

B. navus Cresson. Length 10–16. Ferruginous, the thorax, propodeum and legs more or less black and marked variably with yellow; abdomen mostly ferruginous, banded variably with yellow; no two specimens alike. Both sexes, from Raleigh, Merry Oaks, Durham, Kittrell, Elizabeth City, and Pembroke, May to October.

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